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Scope of Claim for a Patent

[Claim 1]
A Method and System for medium access control in a wireless network, with the intent of enhancing the overall throughput of the network, comprising:

- i an Access Point equipped with a SDMA capable multi-beam antenna and several transceivers such that individual transmit/receive chains may be simultaneously connected to different antenna beams; and
- ii one or more stations that are distributed in the coverage space of the wireless LAN.

[Claim 2]
A timing structure applied to the system described in claim 1, comprising:

- i periodically transmitted Beacon frames announcing the existence of the wireless network and providing a timing reference to the stations in the network;
- ii a "supervised access mode" during which the AP controls access to the wireless channel and coordinates transmissions to/from users so as to exploit the antenna characteristics to achieve several simultaneous transmissions on the same channel at the same time, effectively increasing throughput of the network,
- iii an "unsupervised access mode" during which the AP antenna is configured to an omni-directional pattern, and stations freely access the channel making transmissions using legacy carrier sense techniques; and
- iv signaling by which the AP may either initiate or terminate a supervised or un-supervised access duration.

[Claim 3]
A protocol stack to achieve the method and system claimed in claim 1, comprising:

- i a Medium Access Control (MAC) layer which is responsible for defining the rules of access by which several wireless stations access a shared medium;
- ii a Physical layer which is responsible for the actual transmission and reception of data over the wireless channel; and
- iii a Management entity that manages and coordinates the operation of the layers described in parts (i) and

(ii), with the intent of enhancing the throughput of the entire wireless network.

[Claim 4]
A Medium Access Control (MAC) layer as claimed in part (i) of the protocol stack described in claim 3 and the system of claim 1, comprising:

i a contention-based access mechanism, allowing stations to contend for the transmission medium using a carrier sense mechanism and based on a set of rules;
ii a poll-based channel access mechanism, allowing the AP to fulfill the bandwidth requirements of a particular station while maintaining a level of quality of service that is previously specified by the station; and
iii a beam access coordinator that coordinates the data transfer between the stations and the access point so as to exploit the capabilities of the multi-beam antenna to achieve high throughput, using the medium access mechanisms claimed in parts (i) and (ii).

[Claim 5]
A beacon frame that is broadcast by the AP, announcing the existence of the WLAN and providing a timing reference to the distributed stations in the network, as claimed in part (i) of claim 2, comprising:

i an identification that is unique to the said wireless network, allowing stations to uniquely and unambiguously identify the AP, and hence the particular network;
ii information pertaining to the capability and the protocol of the wireless network, such as specifically defined by the implementation of the access point;
iii information describing the frequency at which beacons are broadcast by the access point in this wireless network; and
iv the duration for which the wireless network will operate in the supervised access mode, with the intent of preventing legacy stations from trying to associate or make a transmission during that phase of the super-frame; and consequently minimizing the impact of such transmissions/collisions on the throughput of the wireless network.

[Claim 6]
Information describing the capability and protocol of the station (or AP), as claimed in part (ii) of claim 5, comprising:

i a protocol reference number, by which the type of medium access control protocol of the station can be ascertained;
ii the antenna type and pattern;
iii the switching/steering capabilities of the antenna; and
iv the direction finding/positioning capabilities of the station.

[Claim 7]
An association request frame that is transmitted by a station wishing to be admitted to a particular wireless network comprising the information elements described in parts (i), (iv) and (v), and optionally parts (ii) and (iii) depending on the network configuration and the station's capabilities, resulting in a reduction in signaling overheads, comprising:
i the wireless network identifier, as described in part (i) of claim 5 that was received in the beacon frame, with the intent of signaling the AP that the station wishes to join the WLAN;
ii the Group identification of the group of beams that covers the station and the station wishes to associate with, as determined by the station by listening for the Beam Start Beacon and the Beam End Beacon, as claimed in claims 11 and 12 respectively;
iii the Beam identification of the specific beam that covers the station and the station wishes to associate with, as determined by the station by listening for the Beam Start Beacon and the Beam End Beacon, as claimed in claims 11 and 12 respectively;
iv the address of the station itself, by which the AP may uniquely identify it in subsequent communications; and
v information pertaining to the protocol features and the capabilities implemented by the station, as claimed in claim 6, with the intent of allowing the AP to determine whether to admit and if so, how best to serve the station.

[Claim 8]
An association response frame that is transmitted by the access point in response to an association request as claimed in claim 7, either accepting or denying the stations request and comprising the information elements described in parts (i), (iv) and (v), and optionally parts (ii) and (iii) depending on the network configuration, the AP's and station's capabilities and the structure of the transmitted association request, claimed in claim 7, comprising:
i the wireless network identifier as described in part (i) of claim 5, with the intent of acknowledging the association request made by the station as claimed in claim 7;

ii the group identification of the group of beams that will be used by the AP in communicating with the station;
iii the beam identification of the beam that will be used by the AP in communicating with the station;
iv the address of the station itself, to which the association response is directed; and
v information pertaining to the status (i.e. the success or failure) of the request and the features and capabilities supported by the AP.

[Claim 9]
An acquisition request by which the AP may request a station to transmit a pre-determined training sequence for a certain duration with the intent of the AP using this transmission to determine the spatial location of the station in relation to it, comprising:
i the address of the station making the acquisition request;
ii the address of the station to which the acquisition request is directed; and
iii the duration of transmission or the length of the training sequence that the addressed station is requested to transmit.

[Claim 10]
A group-ID assign frame that is sent by the AP to a station, assigning it to a particular group of beams for the purpose of further transmit and receive operations, comprising:
i the address of the AP/the ID of the WLAN;
ii the address of the station to which the group-ID assign frame is directed to;
iii the group-ID determined by the AP and assigned to the addressed station; and
iv the beam identification of the beam that the AP will use in subsequent communications with the addressed station.

[Claim 11]
A beam start beacon frame that is broadcast by the AP to stations of a particular beam and group, indicating the start of activity for the users of that beam and group, comprising:
i the address of the AP/the ID of the WLAN, allowing stations to identify the source of the transmission;
ii information pertaining to the capability and the protocol of the wireless network, as claimed in claim 6;
iii the group-ID of the said beam;
iv the beam-ID of the said beam;
v the duration for which the said group will be active i.e. the duration during which the AP will transmit

and receive from users in the said group before switching to another antenna pattern to serve users of another group;

vi the frequency at which the claimed beam start beacon will be transmitted, allowing for stations of the said group and beam to synchronize themselves; and

vii a schedule of the downlink transmissions that the AP will make during the current group duration.

[Claim 12]

A beam end beacon that is broadcast by the AP to stations of a particular beam and group, indicating the end of activity for that set of users, comprising:

i the address of the AP/the ID of the WLAN, allowing stations to identify the source of the transmission;

ii information pertaining to the capability and the protocol of the wireless network, as claimed in claim 6;

iii the group-ID of the said beam;

iv the beam-ID of the said beam; and

v the duration for which the said group will be inactive allowing those users to adopt a mode of operation facilitating a reduction in power consumption.

[Claim 13]

A poll+supervised contention announcement frame that is transmitted by the AP to stations of a particular beam defining the schedule of poll-based medium access and contention based access in the wireless medium, comprising:

i a list of polls allocated to individual stations; and

ii an information element declaring the medium for uplink contention based access for a specified duration, known as the supervised contention access duration.

[Claim 14]

The list of polls allocated to individual stations, as claimed in part (i) of claim 13, comprising:

i the address of the station to which poll-based access is granted;

ii the time of the poll i.e. the time at which the station may begin transmitting;

iii the duration of the poll i.e. the time for which the station may transmit; and

iv the purpose for the poll or grant, with the intent of indicating to the station that the poll is intended to serve a stream for which bandwidth was previously requested, or to solicit an acknowledgement for a previously transmitted downlink frame etc.

[Claim 15]

An AP employing an SDMA capable antenna that is able to form 'sector-shaped' beams having the characteristics of:

i a relatively constant gain in the pass-band, minimizing the variance in the received power level for users belonging to that beam; and

ii a sharp roll-off i.e. a narrow transition width, reducing the interference caused by transmissions in one beam to users of another beam thereby allowing the AP to create more closely spaced beams, resulting in a greater spectral efficiency and consequently higher throughput.

[Claim 16]

A WLAN system using an AP with a multi-beam antenna, as claimed in claim 15 that is able to dynamically form beams with the ability to:

i optimize coverage patterns with respect to spatial distribution of individual users and their traffic loads; and

ii divide the users into groups depending on spatial distribution so as to minimize the variance in the traffic distribution/capacity utilization among users of different groups and beams.

[Claim 17]

A WLAN system, as claimed in claim 16 that uses a timing structure as claimed in claim 2, comprising:

i beacon frames, as claimed in claim 5 that are periodically transmitted using an omni-directional beam pattern so as to provide coverage/detection to new stations that may exist in areas that are not covered by the existing antenna pattern, as explained in part (i) of claim 16;

ii a periodically recurring unsupervised access duration the occurrence of which, new stations may infer from the broadcast beacon, as claimed in claim 5, with the intent of facilitating the detection and association of new stations that may not lie in the coverage area of the existing antenna patterns used during the supervised access durations;

iii the transmission of beam start and beam end beacons, as claimed in claims 11 and 12 respectively, in different beams of a group duration, with the intent of announcing the commencement and conclusion of the corresponding group/beam duration and serving to announce the beam and group-ID of the beam to stations in the coverage area;

iv a station that lies in the coverage area of the existing beams initiating the association signaling, as claimed in claims 7 and 8 that is invoked during

the supervised contention access mode of the said beam, as claimed in part (ii) of claim 27;

v a station that does not lie in the coverage area of the existing beams initiating the association signaling, as claimed in claims 7 and 8 during the unsupervised access duration as described in part (ii);

vi a station as described in part (iv) being assigned a group and beam-ID using the information elements described in parts (ii) and (iii) of claim 8;

vii a station as described in part (v) being assigned a group and beam-ID using the frame described in claim 10; and

viii the AP being able to re-assign a station with a new group-ID at any time, using the signaling claimed in claim 10.

[Claim 18]
A method for determining the group and beam-ID of a station, as required to achieve the functionality required by part (vii) of claim 17 and to handle the case of user mobility, resulting in the invocation of part (viii) of claim 17, comprising the steps of:

i the AP transmitting an acquisition request frame to a station, as claimed in claim 9;

ii the station responding to the request in part (i) with a predetermined training sequence;

iii the AP switching between various beams it is capable of forming and detecting the location of the user as being in the direction of the beam in which the training sequence is received with the highest strength (normalized for beams with different gains); and

iv alternate to (iii), having determined the initial location of the station, using the method and apparatus as described in claim 19 to continually update the user location.

[Claim 19]
A method and apparatus for the AP to continually update the user location based on all uplink transmissions made by the station, allowing the AP to predict the mobility of a station thereby minimizing the use and the overheads incurred by the method in claim 18, comprising the steps of:

i using a primary beam of characteristic claimed in claim 15, which is static and is used to receive the transmission sent by the station;

ii using a secondary steerable beam of characteristic claimed in claim 15 that is swept in that vicinity of the primary beam;

iii determine the angular positions of the secondary beam at which there is a transient in the received power level; and

iv the angular bisector of the angle subtended by the two beam positions in part (iii) above would yield the location of the station.

[Claim 20]

A WLAN system using an AP with a multi-beam antenna, as claimed in claim 15 that is able to cover the entire space with a set of fixed beams with minimal overlap between adjacent beams, resulting in a system with at least two group-IDs.

[Claim 21]

A WLAN system as claimed in claim 20 that may employ a frame structure comprising only the supervised access mode, resulting in a more efficient use of the medium, comprising:

i the transmission of beam start and beam end beacons, as claimed in claims 11 and 12 respectively in the different beams of a group duration, with the intent of announcing the commencement and conclusion of the corresponding group/beam duration and serving to announce the beam and group-ID of the beam to stations in the coverage area;

ii a station detecting the group/beam ID of the area in which he lies indicating this to the AP by means of the association signaling, as claimed in claims 7 and 8, that is invoked during the supervised contention access mode of the said group/beam, as claimed in part (ii) of claim 27;

iii the AP assigning a group/beam-ID to the station in response to the association signaling, as described in part (ii), while accounting for the optimization of traffic distribution of users in different beams across a group in the case of a station that lies in a region of overlap between beams of two groups; and

iv the AP being able to reassign a station with a new group-ID at any time, using the signaling claimed in claim 10.

[Claim 22]

The ability of the AP and stations of the WLAN systems claimed in claims 16 and 21 to detect and counter for station mobility utilizing the steps of:

i the AP detecting station mobility by observing a succession of missed polls or acknowledgements from a station;

ii the AP transmitting a new group-ID assign to a lost station in the beams adjacent to the original beam;

iii the AP upon not being able to re-acquire the station by the method claimed in part (ii), falling back to the acquisition request signaling as claimed in claim 18; and

iv the station on detecting a high occurrence of missed polls or acknowledgements from the AP and/or the loss of the beam start and beam end beacons of the group that it was assigned to, suspends all power-save activity and waits for the AP to re-acquire it, using the steps in parts (ii) and (iii).

[Claim 23]
The division of the supervised access duration claimed in part (ii) of claim 2 into durations for each group in order to facilitate stations of a given group to power-save until its next activity period, comprising the steps of:

i announcing the start and stop of the group's activity duration using the beam-start and beam-stop beacons, as claimed in claims 11 and 12 for users of said group; and

ii synchronizing the transmission of the beam start and the beam end beacons for all beams of a particular group.

[Claim 24]
The inclusion of a downlink schedule element in the beam-start beacon, as claimed in part (vii) of claim 11 with the intent of:

i indicating the schedule of downlink transmissions - consisting of the destination address, the length of the transmission and the time at which said transmission will be made; and

ii indicating the end of the downlink transmission schedule i.e. the transmission time for the poll + supervised contention announcement frame, as claimed in claim 13, with the intent of allowing stations that are not scheduled to receive any downlink transmissions during a given group duration to power-save for the downlink phase of said group duration.

[Claim 25]
The aggregation and synchronization of transmissions on different beams within the same group with the intent of preventing collisions in other beams and collisions at the AP itself due to imperfect isolation in practical RF components, into:

i a downlink phase comprising all downlink transmissions intended for stations of the said group and accounted for in the downlink schedule element claimed in claim 24; and

ii an uplink phase comprising transmissions made from station to the AP using both the polled access and the contention based access mechanisms, as claimed in parts (ii) and (iii), respectively, of claim 4.

[Claim 26]
Aggregation of all downlink transmissions in the downlink transmission phase described in part (i) of claim 25, with the beam start beacon claimed in part (vii) of claim 11, resulting in the reduction of unnecessary overheads and increasing the efficiency of medium usage, by adopting the following steps:

i the use of a shared preamble transmitted by the AP for the beam-start beacon to which all receivers can synchronize; and

ii the elimination of inter-frame spaces between downlink frames.

[Claim 27]
The commencement of an uplink transmission phase using the poll + supervised contention announcement which embeds all the uplink polls as claimed in claim 13, with the intent of minimizing overheads due to individual polls and not requiring the re-synchronization that would be needed to transmit individual polls, as described in claim 25, comprising:

i a polled access phase during which stations transmit for the granted/polled duration as contained in the schedule of the poll + supervised contention announcement frame; and

ii a supervised contention phase, which succeeds the polled access phase and is granted till the scheduled transmission of the beam-end beacon.

[Claim 28]
The use of a guard time that is factored into the schedule claimed in claim 14 and in part (i) of claim 27 that provides for a medium-free duration greater than an RIFS but smaller than a CIFS, between successive polled transmissions, after accounting for the phenomenon of local clock drifts at individual stations.

[Claim 29]
Methods to minimize the collisions caused by rogue carrier-sense stations that do not confirm to the protocol of the WLAN system as claimed in claim 1, comprising the following steps:

i elimination of the variance between downlink transmission times on different beams of a given group by the transmission of 'dummy' or 'pad' data, so as to equalize the transmission time on all beams, preventing a carrier sense based rogue station from detecting the medium to be free and consequently preventing a transmission from it; and

ii stations polled for an acknowledgement in the uplink phase should transmit a negative acknowledgement frame i.e. a station should not ignore an acknowledgement request; thereby not allowing for a gap in the transmission structure to exceed a CIFS duration.

[Claim 30]
A method to detect and counter for the presence of a rogue station in a wireless network as claimed in claim 1, consisting of:

i detection of a rogue-station based on the observance of a failed transmission in all beams at the same instant of time; and

ii upon detecting the presence of a rogue station as in part (i), switching to an unsupervised access mode and signaling the station to move to another channel.

[Claim 31]
A method for the access point in a system as claimed in claim 1 to perform stream admission for a resource reservation request, comprising the steps of:

i resolving the source and destination addresses of the streams to determine if both addresses lie within the same wireless network; and

ii requiring the AP to ensure resource availability on both groups/beams (as opposed to the legacy case of a system with an omni-directional antenna) before accepting the request.

[Claim 32]
A method for the users (AP and stations) of the system claimed in claim 1 to effect power control thereby limiting the interference caused to other users of the channel and resulting in a reduction of transmit power and consequently a saving in battery life, comprising the steps of:

i embedding the transmit power level used to transmit a particular frame/packet in the transmission; and

ii measuring the received power for a given packet transmission at the receiver; and

iii comparing the values obtained by decoding the information encoded in the transmission of (i), and the value of (ii), and adjusting the transmit power of the next packet sent to the transmitter of the packet in (i) correspondingly.

NAME OF DOCUMENT

Specification

TITLE OF THE INVENTION

A Wireless Medium Access Controller based on Space Division Multiple Access

INDUSTRIAL FIELD

The present invention relates to a method and system for medium access control in a wireless network. In particular, this invention describes a new type of WLAN (Wireless Local Area Network) protocol that features a higher throughput compared to existing WLAN devices, through the use of a SDMA (Space Division Multiple Access) capable access point. The system can serve several spatially distributed users simultaneously, thereby resulting in an up to 'n-fold' increase in effective throughput of the WLAN (where 'n' is the number of simultaneous beams and transceiver chains supported by the AP (Access Point)).

BACKGROUND ART

WLANs have several different application areas - they may be used in the enterprise where users may generally be using their wireless enabled notebooks at their desktops and occasionally move them to meeting rooms etc; they may be used in the home, where the access point would be connected to a home-AV server which may consist of a set top box, media player and a portal to the internet and several devices equipped with wireless access - such as display panels, cameras and notebook computers may be accessing the internet or media stored on the home-AV server. WLANs also find application in cellular hotspots such as office building lobbies or coffee shops where mobile users of data services may access them.

IEEE 802.11 (see Non-Patent Literature 1) is a cost effective solution for networking computers and other devices wirelessly. With new developments in signal processing and modulation technology, enhancements to the standard were made in order to support new physical layers with higher data rates (see Non-Patent Literatures 2 and 3). Studies have shown that the key limitation in current 802.11 systems is the MAC (Medium Access

Control) layer, which results in a saturation in throughput with increase in data rates (see Non-Patent Literature 4). While the IEEE 802.11 working group has identified the need for a high throughput WLAN that will be based on both MAC and PHY (Physical) changes to existing WLANs (see Non-Patent Literature 5), one of the key issues identified is the need for support/recognition of legacy systems (see Non-Patent Literatures 5 and 6).

[Non-Patent Literature 1] "Local and Metropolitan Area Networks - Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications", IEEE Std 802.11-1999, IEEE, August 1999

[Non-Patent Literature 2] "Local and Metropolitan Area Networks - Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Higher-Speed Physical Layer Extension in the 2.4 GHz Band", IEEE Std 802.11b-1999, IEEE, September 1999

[Non-Patent Literature 3] "Local and Metropolitan Area Networks - Specific Requirements - Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications: Higher-Speed Physical Layer Extension in the 5 GHz Band", IEEE Std 802.11a-1999, IEEE, September 1999

[Non-Patent Literature 4] Y. Xiao & J. Rosdahl, "Throughput Analysis for IEEE 802.11a Higher Data Rates", doc.: IEEE 802.11/02-138r0, March 2002

[Non-Patent Literature 5] J. Rosdahl et al, "Draft Project Allocation Request (PAR) for High Throughput Study Group", doc.: IEEE 802.11/02-798r7, March 2003

[Non-Patent Literature 6] E. Perahia, A. Stephens, S. Coffey, "Backward Compatability Case Studies", doc.: IEEE 802.11-03/307r0, May 2003

DISCLOSURE OF THE INVENTION

PROBLEM TO BE SOLVED BY THE INVENTION

Based on current applications and those envisioned for the future, the data rates supported by existing WLANs are sufficient (see Non-Patent Literature 7: J. del Prado, K. Challapali, S Shankar and P. Li, "Application Characteristics for HT Usage Scenarios", doc.: IEEE 802.11-03/346r0, May 2003). As WLANs are traditionally time division multiple access

devices, the problem lies in the number of users of high data rate applications that the network can concurrently support. The problem can be generalized as one for the need for higher throughput. The means of achieving higher throughput is to have an increase of data rates measured at the layer above the layer 2 or the Medium Access Control Layer, based on the International Organization for Standardization's (ISO) open systems interconnection (OSI) model. To meet the requirement of increasing the sum of throughput of all wireless stations in one Basic Service Set, where one Basic Service Set contains single wireless Access Point and plural number of wireless stations, the throughput of the wireless LAN system is measured at the Access Point.

While increasing the utilized RF spectrum is one solution, this is not an option - as usable spectrum is a finite resource and is already deployed for other applications. Moreover, due to requirements for backward compatibility with legacy devices, a new system would have to confirm to the spectral masks and channelization that is already in use.

It is an object of the present invention to provide a method and system for medium access control in a wireless network, which can enhance the overall throughput of the network.

MEANS OF SOLVING PROBLEMS

The invention solves the problem by use of a protocol and system based on a multi-beam antenna equipped access point that is capable of performing SDMA. SDMA allows the AP to serve several WLAN users simultaneously on the same frequency channel by exploiting the spatially selective nature of the antenna at the AP. Depending on the number of simultaneous antenna beams that the AP is able to simultaneously form and the number of available transceiver chains at the AP, this can result in an increase in overall throughput of the WLAN network.

In order to achieve the gains in throughput, the invention describes a MAC sublayer and enhancements to the PHY. The changes to the MAC are justified by the inherent requirements of a TDMA/TDD based multi-beam antenna system. In developing the new system, some techniques are also disclosed that would serve to increase throughput and at the same time result in more efficient power consumption, when applied to a WLAN not specifically employing the use of SDMA.

The present invention can be applied in a 802.11 based WLAN consisting of an AP that is fitted with a multi-beam antenna

and is capable of SDMA; and stations, both employing the use of the protocol set out in this text. Stations that detect the presence of the WLAN would first try to associate with it. The invention describes the association procedure for two types of stations - (1) legacy and (2) those equipped with the new protocol. Upon successful association, the AP assigns the station to a particular group and synchronizes the timing of the station such that it can transmit only during the duration assigned to its group. Group formation and assignment may be based on an AP that is capable of determining the positions of individual users and dynamically adapting its beam structure to the user distribution; or, one (an AP) that uses fixed beams that blanket the entire coverage area. The invention describes mechanisms for direction/beam finding needed for group assignment. The AP synchronizes the uplink and downlink phases of transmission across all beams within all groups. Frame aggregation is performed on the downlink to yield a bandwidth saving due to the elimination of inter-frame spaces and preambles. For the uplink, a scheduled poll and supervised contention based access mechanism is described. Mechanisms are disclosed by which stations may perform power control and power saving. Techniques for minimizing the entry of, and facilitating the detection of a non-conforming station (that interrupts the regular communication of the high throughput network) are illustrated and described. Upon detecting the presence of a non-conforming/rogue station, the AP may signal it to move to another channel.

The invention in its entirety describes a system and protocol for a WLAN, with the primary intent of achieving high throughput.

EFFECTS OF THE INVENTION

The present invention identifies the AP as being the bottleneck for all traffic in a wireless LAN. Applying the invention in a WLAN results in an up to 'n-fold' enhancement in throughput, resulting in a network that is capable of serving more users, with higher application data rates, and a better quality of service. The techniques described in this invention help to push the implementation complexity and cost of the network to the AP, while minimizing the changes needed at the station/user-equipment. The protocols set out in this invention facilitate the detection of legacy network devices and their steering to other channels allowing for the optimization of throughput on the channel that is allocated for high throughput WLANs. The invention also describes power control techniques that help to minimize the impact of devices using the present invention on other users of the same channel.

Power-save techniques are also described in this invention. Collectively these techniques result in a reduction in battery requirements, leading to the design of smaller and lighter terminals/devices.

In conclusion, the impact of the present invention can be summarized as two-fold: (1) It results in an increase in the overall throughput of the WLAN; and (2) It facilitates the design and manufacture of low cost, low complexity and small form-factor user equipment/terminals.

BEST MODE FOR CARRYING OUT THE INVENTION

An apparatus and mechanism for the terminals and access point in a WLAN network employing Space Division Multiple Access to perform Medium Access Control is disclosed in this section. To help understand the invention, the following definitions are used:

A "WLAN" refers to a wireless local area network. It contains an arbitrary number of devices or nodes in order to provide LAN services to mobile terminals through wireless access technologies.

A "Station (STA)" refers to a device that is capable of accessing the service provided by the WLAN.

An "Access Point (AP)" refers to the station in the WLAN that is responsible for controlling access to the network and maintaining timing in it. Among other services, it acts as a bridge for the stations in a WLAN to access devices in other networks.

"Space Division Multiple Access (SDMA)" refers to the access mechanism by which multiple wireless transceivers can simultaneously use the same spectrum to communicate, by virtue of their physical separation in space and the ability of the transceiver to use directed beams to transmit and receive the signal.

"medium" refers to the wireless channel in which the WLAN is operating.

A "Multi-beam Antenna" refers to an antenna system that is capable of forming different beams in different directions with minimum cross-over/inter-beam interference, with the intent of achieving SDMA.

"Medium Access Control (MAC) layer" broadly refers to the network protocol that is used by individual stations in order to gain access to the network medium.

"Physical (PHY) layer" refers to the actual transceiver that transmits and receives signals in the network. It can be generalized to consist of several sub-layers such as a convergence layer from the MAC and a control layer etc.

A "beacon-frame" is a frame that is periodically transmitted by the AP, typically denoting the start of a super-frame and carrying network specific information for all STAs in the WLAN.

"downlink" refers to the transmission link in which communication takes place from the access point to the stations.

"uplink" refers to the transmission link in which communications takes place from the stations to the access point.

A "super-frame" refers to the network frame timing structure enforced by the access point or network-coordinator upon all associated nodes.

"supervised access mode" refers to a mode of operation in the WLAN super-frame in which the stations confirm to certain rules of access as defined by the AP or the network coordinator.

"unsupervised access mode" refers to a mode of operation in the WLAN super-frame in which stations perform unregulated contention based access to the medium.

A "group" refers to a set of stations, which can be simultaneously covered by the AP through the formation of one or many non-overlapping beams.

A "group-ID" refers to an identification assigned to stations belonging to a particular group, by which a collective command (multi-cast) may be sent to them.

"group duration" refers to the amount of time for which the AP forms antenna beams to cover a particular group of users.

A "beam-start beacon frame" refers to a message sent out by the AP, informing the users of the relevant group and beam of the WLAN of the commencement of their group duration.

A "beam-end beacon frame" refers to a message sent out by the AP, informing the users of the concerned group to power-off for the other group's duration.

A "Poll + Supervised Contention Access frame" is a frame sent by the AP, announcing to the users in a particular group and beam, the schedule of the uplink transmissions and the supervised contention access period.

A "Response Inter-Frame Space (RIFS)" is the smallest time duration between successive transmissions from different stations in a WLAN. It is typically smaller than the minimum duration required for medium preemption, thereby allowing it to be used for response and acknowledgement frames.

A "Pre-emption Inter-Frame Space (PIFS)" is the time duration that is observed by an AP wishing to gain access to the medium. A PIFS is larger than the RIFS but is smaller than the CIFS thereby allowing the AP a higher priority of access than a STA.

A "Contention Inter-Frame Space (CIFS)" is the smallest amount of time that a station must observe the medium to be

idle for before beginning a contention i.e. a non-polled transmission. A CIFS is the largest of the inter-frame spaces.

A "rogue station" is defined as a station that does not fully comply with the protocols of the WLAN or is a station that is not properly synchronized with the timings of the current LAN, who behaves in a manner that results in collisions/interference in the WLAN.

In the following description, for purposes of explanation, specific numbers, times, structures, protocol names and other parameters are set forth in order to provide a thorough understanding of the present invention. However, it will be apparent to anyone skilled in the art that the present invention may be implemented without these specific details. In other instances, well-known components and modules are shown in block diagram in order not to obscure the present invention unnecessarily.

For a thorough understanding of the invention, here below, some operation sequences, information data structures and techniques for calculation are given. Certain data structures are used and they only serve as an example of the implementation of the present invention. It is obvious to the person skilled in the art that in real implementation, new information could be added, and certain parts could be omitted depending on the actual situation they are used in.

Figure 1 shows a typical WLAN network consisting of an AP (101) and several STAs (102~104). Due to the requirements of portability and mobility, STAs are generally small and use a simple antenna, which may have an omni-directional or a near omni-directional beam-pattern. On the other hand the access point which is usually a fixed network infrastructure device can have the ability to form different spatially separated beams (105~107) with minimal crossover/interference between them.

The multi-beam antenna equipped AP will be able to form a set of beams in different directions, including an omni directional beam pattern. When a STA powers on, it scans for the presence of a wireless network. First, it will detect the beacon frames (201) that are broadcast by the AP at fixed intervals for the purpose of synchronizing the stations and informing them of network specific information. Beacon frames are broadcast periodically, so as to synchronize the timing of all stations, update existing stations and inform new stations of network specific information. The duration between two successive beacons is referred to as a super-frame (202). In order to exploit the benefits of a multi-beam antenna (which will reside at the AP) based WLAN, the AP needs to coordinate the formation of beams so as to match the transmit and receive

timings of stations, at the same time optimizing the bandwidth usage of the channel. Two modes of operation for the MAC super-frame are identified - (i) supervised access mode (203) (during which the AP uses the multi-beam antenna system), and (ii) unsupervised access mode (204) (during which the AP uses an omni-directional antenna pattern, with the primary intention of serving legacy stations). For purposes of explanation, Figure 2 depicts the super-frame as being divided into one instance of each of the two access modes. However, this does not preclude the more general case of several instances of either mode occurring in a super-frame. The AP may signal the end of either access mode using the "supervised access end frame" (205) and the "unsupervised access end frame" (206), respectively. With the intent of optimizing bandwidth usage, these frames may also be aggregated with other frames sent by the AP, such as the beacon for example.

To enable data transmission based on the above scenario, the protocol stack, shown in Figure 3 will be used to support the high throughput data transmission in the WLAN. Medium Access Control Techniques are largely classified into two broad types - contention-based (301) and poll-based (302), both of which are similar to those described in Non-Patent Literature 1 mentioned above and Non-Patent Literature 8 ("Draft Supplement to LAN/MAN Specific Requirements - Part 11: Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications: MAC Enhancements for Quality of Service (QoS)", IEEE Std 802.11e/D4.2, February 2003). The Contention based access mechanism is equivalent to the Distributed Coordination Function (DCF) in Non-Patent Literature 1 and the HCF contention-based channel access or Enhanced Distributed Coordination Function (EDCF) in Non-Patent Literature 8. The poll-based channel access is similar to Point Coordination Function (PCF) in Non-Patent Literature 1 and the HCF controlled channel access in Non-Patent Literature 8. In the above description, HCF refers to the Hybrid Coordination Function.

In Figure 3, the Beam Access Coordinator (303) allows the operation of the WLAN in the high throughput mode, coordinating the data transfer between AP and STAs so as to exploit the capabilities of a multi-beam antenna in the network to achieve high throughput. The MAC (304) and PHY (305) entities of the protocol stack depicted in Figure 3, are controlled by the Management Entity (306)

Central to this invention is the Beam Access Coordinator which facilitates the use of the two coordination functions described above, and other new access mechanisms to achieve simultaneous transmission and reception of several data streams from an AP capable of multi-beam formation.. Based on

the beam formation capabilities, the Management Entity (306) using the Beam Access Coordinator can further control the data exchange using the polled and contention based access mechanisms.

A Beacon frame is a broadcast frame announcing the existence of the WLAN, its ID and serving as a timing reference. The beacon may also include the capabilities/feature set of the WLAN which may include a protocol reference number (high-throughput/legacy station), the antenna type (omni/directional), the antenna type (dynamic beam forming/fixed beam) and direction finding capabilities. It may be described by the structure below:

```
Beacon
    {
    WLAN ID   /*unique identifier for the AP & WLAN*/
    WLAN Capability/Protocol Type /*protocol set &
        features of the AP*/
    Beacon Repetition Rate   /*rate of recurrence of
        this frame*/
    Supervised Access Duration   /*duration of multi-
        beam operation*/
    }
```

An association request is a command sent by a STA requesting to join a particular WLAN and may contain the following information elements.

```
AssociationRequest
    {
    WLAN ID   /*unique identifier for the AP & WLAN*/
    Group ID  /*common identification for a set of
        beams*/
    Beam ID   /*identification of an individual beam*/
    STA ID/Address /*unique address of the station*/
    STA Capability /*protocol set and features of the
        station*/
    }
```

An association response is a command/frame sent by the AP to a STA that has previously requested an association, either accepting or rejecting the STAs request. It may contain the following information elements.

```
AssociationResponse
    {
    WLAN ID   /*unique identifier for the AP & WLAN*/
    Group ID  /*common identification for a set of
        beams*/
    Beam ID   /*identification of an individual beam*/
```

```
        STA ID/Address /*unique address of the station*/
        Association Status  /*result of the association
             request*/
        }
```

An acquisition request is a command sent by the AP requesting the station to send it a training sequence for the purpose of determining the direction of the AP relative to the station. The information content of an acquisition request may be described by the structure:

```
   AcquisitionRequest
        {
        Source Address (AP) /*unique identification of
             initiator of the frame*/
        Destination Address /*unique identification of
             addressed station*/
        Duration/Length of Training Sequence
        }
```

A group-ID assign is a command frame that is sent by an AP to a station, assigning it to a group of beams. The information content of a Group-ID assign may be described by the structure:

```
   GroupIDAssign
        {
        Source Address (AP) /*unique identification of
             initiator of the frame*/
        Destination Address /*unique identification of
             addressed station*/
        Group ID  /*common identification for a set of
             beams*/
        Beam ID   /*identification of an individual beam*/
        }
```

The Beam Start Beacon is a frame broadcast to STAs of a particular beam and group, indicating start of activity of that beam/group and may contain the following information elements:

```
   BeamStartBeacon
        {
        WLAN ID   /*unique identifier for the AP & WLAN*/
        WLAN Capability/Protocol ID   /*protocol set &
             features of the WLAN*/
        Group ID  /*common identification for a set of
             beams*/
        Beam ID   /*identification of an individual beam*/
        Group Duration /*active time for current Group of
             beams */
```

```
Group Repetition Rate    /*rate of recurrence of
     this frame*/
Downlink Schedule   /*timing structure for downlink
     transmissions*/
}
```

The Beam End Beacon is a frame that is broadcast to STAs of a particular beam and group, indicating end of activity of that beam/group and may contain the following information elements:

```
BeamEndBeacon
     {
     WLAN ID   /*unique identifier for the AP & WLAN*/
     WLAN Capability/Protocol ID   /*protocol set &
          features of the WLAN*/
     Group ID  /*common identification for a set of
          beams*/
     Beam ID   /*identification of an individual beam*/
     Sleep Duration /*duration of inactivity for current
          beam */
     }
```

The Poll+Supervised Contention Announcement Frame is a frame that is sent by the AP to a group of STAs in a particular beam defining the structure for poll based medium access and contention based channel access. The information contained by it may be described by the structure:

```
Poll+SupervisedContentionAnnouncement
     {
     {AddressSTA1, GrantTime1, GrantDuration1,
          GrantType1}
     {AddressSTA2, GrantTime2, GrantDuration2,
          GrantType2}
     :
     :
     {AddressSTAN, GrantTimeN, GrantDurationN,
          GrantTypeN}
     {Group Address, GrantTime, GrantDuration,
          SupervisedContention}
     }
```

The SDMA capable WLAN may have AP's with different antenna capabilities. One kind of system may be able to choose between different sets of beams from a library of array weighting coefficients so as to optimize the coverage area with respect to the spatial distribution of users. An example of such a system that is capable of forming three simultaneous beams (i.e. having three transmit/receive chains at the AP) is shown in Figure 4. In the Figure, the AP (401) uses a wide-beam (402) to cover a space with low user/traffic density and a narrow beam (403) to cover a space with high user/traffic

density. The objective of the AP in doing so is to minimize the variance in the traffic distribution/capacity utilization among users of different groups and beams, so as to have similar traffic/utilization patterns across all beams in a group. In a scenario where all the users cannot be covered simultaneously using different beams, while trying to balance the number of users/traffic across different beams, the AP may resort to grouping the users into two sets of beams, illuminating the two sets in an alternate manner. An example of two sets (404 and 405) of three non-overlapping beams is shown in Figure 5. Based on the above scenario, a similar case with overlapping beams may also be envisioned.

In a system as described in Figure 4, the AP may not cover the entire user-space with its beams. It hence needs to periodically revert to an unsupervised access mode, as depicted in Figure 2 in order to detect the presence/allow new stations to associate with it. A new station detects the beacons and issues an association request in the un-supervised access mode (i.e. when the AP is in an omni mode). The *AssociationRequest* may take a structure as described previously with the Group ID and Beam ID fields being set to null values. Correspondingly, if the AP decides to accept the station, it may return an association response with the Group and Beam IDs set to null. The station may be assigned a group/beam ID using the *GroupIDAssign* frame as will be described subsequently.

The formation of beams for a system as described by Figure 4 and above is dependent on the knowledge at the AP of the user's location/direction. In the following, we describe a method and apparatus by which the AP is able to acquire a STAs relative direction, using the messaging as described in Figure 6. After the association signaling (502) is complete, the AP sends out an *AcquisitionRequest* command (501) to the STA, containing information as described by the structure previously. The station responds after a RIFS (503) duration with an acquisition response (504), which consists of a pre-determined training sequence (505) transmitted for a certain duration (as dictated by a field in the frame). The duration of the training sequence may depend on the implementation of the AP - number of beams, beam switching speed and receiver lock time. As stated above, the acquisition time depends on system implementation. Hence, some systems may be able to perform direction determination using the preamble of an uplink frame as the training sequence, obviating the need for the training sequence of Figure 6.

Depending on system implementation, direction may (need to) be determined to varying degrees of accuracy by the AP. One method is: During transmission of the training sequence, the

AP will switch between the various beams available to it. The beam in which the user's transmission is received with the maximum signal strength (after normalizing for differences in power gains in different beams) would determine the direction of the user.

Ideally, individual beams formed by the AP should be of the shape of a 'sector', with minimal variation in gain within the desired beam-width and a very sharp roll-off thereafter. While the advantage of such a design is that beams carrying different transmissions may be placed close to one-another, the disadvantage is that when a user moves from one beam to another, he almost disappears at once. The messaging technique described in Figure 6 will resolve this. However, this results in substantial overheads, as the system must revert to the unsupervised access mode in order to perform this. An apparatus for continually updating the AP with the STA location is depicted in Figure 7 and described by the flowchart in Figure 8 and as follows - While the primary beam (601) is being used by the AP (602) to receive a packet from the user of interest (603), the secondary beam (604), which is of similar sector shaped design, is swept (606) in the vicinity of the primary beam. If each sweep position is characterized by a beam angle (605), then by virtue of the beam shape, the received signal power level (measured by (607)) will have transients (detected in (608)) at two different locations - namely the edge points of the beam. The AP can then ascertain (609) the location of the user to be the bisector of the angle subtended by the two beam positions at which the transient occurs. This location determination can be done during an uplink transmission, as well as during the reception of acknowledgement frames at the AP (610). By performing this kind of dynamic update of user position, the AP can adjust its beam pattern when needed and appropriately reassign the STA to a different Group, using the *GroupIDAssign*, when needed; reducing the use of the acquisition request signaling, resulting in a more efficient use of the medium.

Depending on the implementation of the transient received power detector, as in (608), there will be a trade-off between detection time and accuracy of beam coverage. It is also plausible that the detector accounts for the interference received from adjacent beams and/or channel information in detecting the transient. An accurate determination of the received power, as in (608) in a simplistic manner will enable the algorithm depicted in Figure 8 to exit the steering loop and come to closure on the station's location.

Having determined the location of users, the AP can divide them into groups - if all cannot be simultaneously covered and depending on their spatial distribution, traffic distribution

and the number of beams the AP can simultaneously form. Likewise, appropriate Group and Beam IDs are assigned to individual stations. Despite employing a continual update mechanism as depicted in Figure 7, there is a possibility that the STA moves out of a beam space without being detected by the AP - this is particularly likely for STAs in which the uplink traffic is highly infrequent. Such a scenario may be detected by the AP in the form of missed polls or acknowledgements from the STA. The AP may try to acquire the STA by issuing a new *GroupIDAssign* in a beam that is adjacent to the original beam of the STA. In the worst case, the AP may need to issue a new acquisition request. In the case of the STA, moving out of the beam-space would imply that it no longer detects the *BeamStartBeacon* and the *BeamEndBeacon* of the group that it belonged to. In such a scenario, the station should suspend all power-save activity and listen for a new *GroupIDAssign* or an *AcquisitionRequest*. Once the station has been re-acquired by the AP and re-synchronized with the beam start and beam end beacons, the STA may reenter the power-save state, where it sleeps for the other group's duration.

Another AP multi-beam antenna system may be envisioned, which employs the use of fixed beams to cover the entire space. An example of such a system is shown in Figure 9, where the AP (701) uses two sets (702~703) of three beams each in order to cover the entire space. As was mentioned previously, a desirable characteristic in multi-beam systems is to have a 'sector-shaped' beam - i.e. one with a uniform pass band gain and a very sharp roll-off. In practice, however it is not possible to achieve a very sharp roll off, resulting in a certain amount of overlap (704) between adjacent beams, as shown in Figure 10. Based on such a scenario, it is apparent that there must be at least two beam groups with beams of alternating groups placed adjacent to one-another. In a system as depicted in Figure 9, direction searching is simplified to merely switching between two groups to determine the beam in which the user lies. Hence it is envisaged that the AP is able to make use of the preamble of the *AssociationRequest* signaling to determine the beam and group of the user, which may be correspondingly assigned using the *Beam ID* and *Group ID* during the *AssociationResponse* phase. Due to the overlap between adjacent beams, there may be two scenarios - (1) a station lying in a non-overlapping region and hence illuminated by only one beam; and (2) a station lying in an overlapped region. Stations in an overlapped region may be assigned to either group. This may be requested by a station (through use of the *GroupID* and *BeamID* fields of the *AssociationRequest* frame) and it is upto the AP to accept the decision of which may be based on a load/traffic balancing algorithm that is performed at the AP in order to minimize the

variation between utilized bandwidth in different beams of different groups.

Unlike the dynamic beam system that optimizes beam coverage according to user location and traffic distribution, the fixed beam system uses beams to cover the entire space. Hence, a station that powers on and scans the medium would detect either one or two sets of *BeamStartBeacons*, depending on whether it lies in the non-overlapped or overlapped regions respectively. In the case of presence in the non-overlapped region, the station can determine the *BeamID* and *GroupID* through the detected *BeamStartBeacon* and *BeamEndBeacons*. It can include this information in its association signaling that is performed during the uplink supervised contention phase of that beam. In the overlapped case, the station would be able to initiate an *AssociationRequest* during the supervised contention access phases of either group, indicating that it can detect both groups. During the downlink phase, the AP may respond with an *AssociationResponse* and embed information acknowledging the admittance of the station to its desired group, or indicating admittance to another group (for factors determined by the AP, such as load/traffic distribution etc.).

It is highly likely that a STA may move over time and fall in the coverage of another beam/group. The AP may detect this in the form of missed polls or acknowledgements from the station. Corrective action may be taken in the form of transmitting a new *GroupID* or polling it in beams adjacent to the original one. In the worst case, a new acquisition request may have to be issued. A station that moves from one group's beam to another would no longer detect the beam-start and beam end beacons of the original group that it belonged to, at the scheduled times. In this event, the station should suspend all power-save activity and listen for the new group-ID assign that would be sent in the adjacent group duration. Having acquired a new group-ID and synchronized with the beam start and end beacons, the station may re-enter the power-save state, where it sleeps for during the other group's duration.

Based on the description, above, a WLAN with a multi-beam capable antenna capable of covering the entire space would not need to employ the use of a regularly recurring unsupervised access period. However, it may need to revert to the unsupervised access mode when a legacy station is detected. For a dynamic beam forming system, a regular unsupervised access period is needed, so as to allow for the detection and association of new stations that may not lie in the beam space initially covered by the AP. Hence there is a tradeoff between the two systems - while the dynamic beam forming system provides coverage over areas only where users exist and hence makes more optimal use of all the beams of the supervised

access duration, it needs a periodic unsupervised duration for detecting new stations; the fixed beam system covers space uniformly, irrespective of user distribution but only needs to revert to an un-supervised access mode when legacy stations are detected.

Figure 11 is a HMSC depiction of the start-up sequence adopted by a station for the two different antenna systems (dynamic beam-forming & fixed beam forming) described above. Literal 801 depicts the scan and detect phase, in which the station detects the nature of the WLAN. For a fixed beam system (802), the station goes through the steps of association and group assignment as described above, by following the message path depicted by literal 803. For a dynamic beam system (804), the station follows the steps described above and marked by literal 805. As can be seen from the figure, the location of the station may be acquired using an explicit training sequence shown in Figure 6, and marked by literal 806, or it can be acquired using the preamble of a frame transmission, as marked by message path 807.

Based on the example of two groups with three beams each, Figure 12 depicts the timing structure of the supervised access period of the super-frame. Literal 901 marks the *BeamStartBeacon* frame that is broadcast by the AP on beam 1 of group 'A'. Likewise the *BeamStartBeacons* for beams 2 and 3 of Group 'A' are collectively marked by (902), while literal 903 collectively marks the *BeamStartBeacons* of Group 'B'. Each beam start beacon announces the start of activity for users of a particular group in a particular beam and announces the duration of the supervised access mode dedicated to that group (*GroupDuration*) and the timing of the next group duration for users of the current group (*GroupRepetitionRate*). Note that in the structure we represent this as a rate based parameter - however, it may also be represented as a time based parameter. Hence during group period 'A' (904), users belonging to group 'B' must be silent and may choose to power-save and likewise during group-period 'B' (905). An alternate mechanism that may be used in conjunction with the described above is for the AP to broadcast a *BeamEndBeacon* informing stations of a particular group not to access the medium, or to power-save till the next group duration or unsupervised access period. *BeamEndBeacons* for groups 'A' and 'B' are collectively marked by literals (906) and (907) respectively. Note that while Figure 12 uses two group durations - one for each group, to illustrate the concept of division of time within a supervised access mode, this does not preclude the more general case of several alternating group durations within the same supervised access period.

The *DownlinkScheduleElement* contained in the *BeamStartBeacon* is a structure containing the medium allocation/polls for the downlink transmissions of various associated STAs. To facilitate a finer granularity of power-save - i.e. power-save for stations not scheduled to receive any downlink transmissions, the *DownlinkScheduleElement* can announce the timing of the end of the downlink transmission phase or the start of the *Poll+SupervisedContentionAnnouncement* frame that is used to initiate the uplink phase, as described in subsequent sections of this embodiment.

To prevent any collisions in other beams (due to the assumption that stations use omni antennas) and collisions created at the AP itself (due to imperfect isolation in the practical design of RF components), the transmit and receive operations must be synchronized at the AP for all beams at all times. Building upon the example of Figure 12, Figure 13 shows the Group 'A' duration (1001) of the supervised access duration in detail. The separation of the downlink and uplink phases of the transmission and their synchronization across beams is marked by literals (1002) and (1003) respectively. Note that the figure shows the division of the group 'A' duration into one uplink and one downlink phase for ease of illustration and explanation. However this does not preclude the occurrence of several uplink and downlink phases within a group duration.

In order to make efficient use of bandwidth, frames in the downlink (i.e. frames originating at the AP) of a particular beam can be aggregated. This will facilitate the elimination of the inter-frame space durations between frames that is conventionally used to distinguish between two independent transmissions (downlink transmissions are not entirely independent as they all originate from the AP). As a consequence of the elimination of the inter-frame spaces, only one preamble (1004) is needed at the start of the frame, leading to a further reduction in bandwidth usage. All receivers can synchronize with this preamble and rely on their MAC layers to interpret and access the portions of the downlink transmission that are relevant to it. As shown in the figure, the downlink transmissions may even be aggregated with the beam start beacon since they have the same source (the AP). As mentioned previously, the beam start beacon (1005) contains information on which stations would receive data during the downlink transmission - stations not on this list may go into power-save after deciphering this information, for the duration of the downlink phase.

Upon completion of the downlink transmission on all beams within a certain group, the AP issues an uplink request/poll. This may be aggregated with the longest downlink transmission

in the group (Beam 2 in the example of Figure 13). However, doing this aggregation precludes the use of power-save among stations belonging to that beam and group to which there were no scheduled downlink transmissions. This is because a station that power-saves would loose synchronization with the downlink transmission. Hence, Figure 13 shows the *Poll+SupervisedContentionAnnouncement* frame (1006) being transmitted one RIFS (1007) after the longest downlink transmission, and being synchronized on all beams. This is to allow for stations that were in power-save mode during the downlink duration to re-synchronize with the AP in order to receive the *Poll+SupervisedContentionAnnouncement* frame.

As depicted by the structure previously, the *Poll+SupervisedContentionAnnouncement* frame (1006) announces a schedule for uplink transmissions that the AP wishes to receive from stations in a particular beam. Each field in the structure is a structure in itself, detailing the grant/poll to a particular station (*AddressSTA*). The *GrantTime* denotes the time at which the intended station is to commence its transmission while the *GrantDuration* denotes the length of time or the duration for which the STA is given medium access. Using the *GrantType* field, the AP may indicate to a STA the intention of the poll - i.e. a response to a reservation request; or a request for an acknowledgement to a previously transmitted downlink frame etc. The last element of the *Poll+SupervisedContentionAnnouncement* frame announces the start of the supervised contention access duration to all users of the given group and beam. Note that contention based traffic can only be acknowledged in the next downlink cycle. All uplink access to the channel must cease one RIFS prior to the beam-end beacon frame (1008), allowing the AP to take control of the medium again.

The AP must embed multiple polls in the *Poll+SupervisedContentionAccess* frame (1006) to allow for the contention based transmission of uplink packets of different lengths on different beams - If the AP were to poll sequentially it would need to synchronize or seize the medium on all beams before sending a poll-frame (which is a downlink transmission). This would result in unnecessary bandwidth wastage, especially in scenarios where packet sizes on different beams differ widely. Also, as no assumption is made about the capabilities of the station's antenna, an omni directional uplink transmission from any one station would prevent the other stations from observing the medium to be free, preventing them from making a transmission by means of legacy carrier sense techniques. Hence, during the polled uplink access, a station that is polled should rely on the timing information contained in the poll and ignore the carrier sense mechanism. However, should power control

(described subsequently) between stations be excellent, the carrier sense mechanism may detect the medium to be free (when there is actually a transmission going on). It is anticipated that such a scenario would only occur for users of a group that are in beams that are sufficiently far apart - i.e. it is assumed that two stations in a beam are not hidden from one another. As the AP employs directive antennas it can receive two spatially separated uplink transmissions. Consequently, the multi-beam antenna MAC would aid throughput enhancement in the supervised contention access period as well.

It may be noted that a certain gap between two successive uplink transmissions is needed in order to allow the receiver at the AP to synchronize with the transmission from the next station. This "guard time" (marked by literal 1013 in Figure 13) is also needed in order to prevent two scheduled transmissions from colliding due to drifts and inaccuracies in their local clocks. The guard time should be implemented in a manner so as to allow the actual time between two successive transmissions to be less than or equal to a CIFS duration, while being greater than an RIFS duration.

In the downlink duration (1002) in Figure 13 it is observed that there is a possibility of variation in the downlink transmission times in different beams. This may arise due to there being different traffic loads in different spatially separated users. As transmissions from the AP are directional in nature, as previously explained, only one group of users "hears" them at one time. In the example of Figure 13, this is Group 'A'. Based on the protocol described above, Group 'B' users are not to transmit during this time. However, a rogue station (which may be a legacy contention based access WLAN terminal) and is positioned to lie in the coverage area of Beam 1 of Group 'A' would detect the medium to be free during the duration marked by literal (1009). In order to reduce the probability of collisions (and thereby increase the throughput of the WLAN), the AP can adopt a mechanism wherein it transmits dummy data so as to align the transmission time with beam 2. An example of this is shown in Figure 14, where literal (1010~1011) marks the transmission of dummy data in beams 1 and 3, so as to align itself with beam 2 (1012), ensuring that a rogue station that is co-located in that beam cannot attempt contention based access during the downlink phase. While this mechanism prevents medium access by a rogue station, which is co-located with the currently active group (Group 'A' in this example), thereby reducing the collision probability, it cannot take care of a scenario wherein a rogue station lying in Group 'B' space makes a transmission during Group 'A' duration. While the AP cannot prevent such a scenario, it can detect it by examining the acknowledgements that are received during the uplink phase. If a negative

acknowledgement is received for all the frames that were downlinked at the same time on different beams, then the most probable cause is that of a rogue station. The AP can accordingly proceed to take corrective action such as switching to an unsupervised access mode and detecting the rogue station and even requesting it station to move to another channel etc.

In the uplink, a station that is polled for an acknowledgement during the *Poll+SupervisedContentionAnnouncement* should respond with a negative acknowledgement frame if the downlink data was received in error. In other words, a station should transmit both negative and positive acknowledgements. This will prevent the timing structure of the supervised access period from being altered due to a missing frame, also preventing a "medium silence duration" greater than a guard-time (which is smaller than a CIFS and greater than a RIFS) and consequently preventing medium access by a contention-based rogue station. The same holds good for a polled bandwidth allocation - a station should maintain a transmission for the allotted duration even if it has no data to send.

For the purpose of transmissions of streams requiring an assured level of QoS, it is anticipated that the AP provides a class of service (scheduled polling) that meets certain bandwidth and delay requirements as specified by the station during the reservation request phase. An AP may deny a reservation request depending on its bandwidth availability. In traditional WLANs (i.e. legacy systems not employing the use of a multi-beam antenna), the medium is shared by all stations at the same time. Hence in terms of bandwidth reservation, the AP has to keep track of only one (omni directional) beam. A multi-beam antenna based WLAN, divides space (and hence the users that are in it) into multiple beams. Consequently a reservation request made by a station in one of the beams will allow the AP to only facilitate a reservation for that beam. The sink of the stream may be in a different beam or may be in another network that is accessed through the AP. Hence, a multi-beam antenna based WLAN would require a reservation request to contain the destination address of the stream for which the reservation is being made. Based on this information the AP will determine the location of the destination station/traffic sink. If the sink is located in the WLAN itself, the AP would need to ensure that adequate resources are available in both the uplink and the downlink beams before accepting the reservation request.

The use of a multi-beam antenna based system results in a variable (dependent on direction and beam-pattern) gain component being added to the link budget. This gain may be

used to reduce the transmit power requirements for either station or the access point resulting in a saving of battery life and the mitigation of interference to other users of the same channel. Transmit power may be adjusted at a rate as high as on a per packet basis with a response time of one packet. Since WLANs are time division duplex (TDD) i.e. they use the same channel on both the uplink as well as the downlink, the measurement made on one link being applicable to the other. To achieve power control, the following mechanism is described: A station (or AP) transmitting a packet to an AP (station) includes the transmit power level used in the frame. This may be encoded in either the payload (which is interpreted by the recipient's MAC sub-layer) or in the header of the physical convergence sub-layer (which contains information such as the data rate used, the scrambler information etc). A receiver of the original transmitted frame may compare the actual received power (determined by measuring the received signal strength) with the actual power level that was used for transmission (that is encoded in the transmitted frame) and determine the surplus power that was used during the transmission. Consequently, in its next transmission, the station can reduce its transmitted power by this surplus amount, resulting in a net reduction in power consumption and interference generated to other users of the same channel.

As explained above, the features of the invention can be sorted out as follows.

(1) A Method and System for medium access control in a wireless network, with the intent of enhancing the overall throughput of the network, comprises (i) an Access Point equipped with a SDMA capable multi-beam antenna and several transceivers such that individual transmit/receive chains may be simultaneously connected to different antenna beams and (ii) one or more stations that are distributed in the coverage space of the wireless LAN.

(2) A timing structure applied to the system described in (1) above, comprises (i) periodically transmitted Beacon frames announcing the existence of the wireless network and providing a timing reference to the stations in the network, (ii) a "supervised access mode" during which the AP controls access to the wireless channel and coordinates transmissions to/from users so as to exploit the antenna characteristics to achieve several simultaneous transmissions on the same channel at the same time, effectively increasing throughput of the network, (iii) an "unsupervised access mode" during which the AP antenna is configured to an omni-directional pattern, and stations freely access the

channel making transmissions using legacy carrier sense techniques, and (iv) signaling by which the AP may either initiate or terminate a supervised or un-supervised access duration.

(3) A protocol stack to achieve the method and system described in (1) comprises (i) a Medium Access Control (MAC) layer which is responsible for defining the rules of access by which several wireless stations access a shared medium, (ii) a Physical layer which is responsible for the actual transmission and reception of data over the wireless channel, and (iii) a Management entity that manages and coordinates the operation of the layers described in parts (i) and (ii), with the intent of enhancing the throughput of the entire wireless network.

(4) A Medium Access Control (MAC) layer as described in part (i) of the protocol stack described in (3) and the system of (1), comprises (i) a contention-based access mechanism, allowing stations to contend for the transmission medium using a carrier sense mechanism and based on a set of rules, (ii) a poll-based channel access mechanism, allowing the AP to fulfill the bandwidth requirements of a particular station while maintaining a level of quality of service that is previously specified by the station, and (iii) a beam access coordinator that coordinates the data transfer between the stations and the access point so as to exploit the capabilities of the multi-beam antenna to achieve high throughput, using the medium access mechanisms described in parts (i) and (ii).

(5) A beacon frame that is broadcast by the AP, announcing the existence of the WLAN and providing a timing reference to the distributed stations in the network, as described in part (i) of (2), comprises (i) an identification that is unique to the said wireless network, allowing stations to uniquely and unambiguously identify the AP, and hence the particular network, (ii) information pertaining to the capability and the protocol of the wireless network, such as specifically defined by the implementation of the access point, (iii) information describing the frequency at which beacons are broadcast by the access point in this wireless network, and (iv) the duration for which the wireless network will operate in the supervised access mode, with the intent of preventing legacy stations from trying to associate or make a transmission during that phase of the super-frame, and consequently minimizing the impact

of such transmissions/collisions on the throughput of the wireless network.

(6) Information describing the capability and protocol of the station (or AP), as described in part (ii) of (5), comprises (i) a protocol reference number, by which the type of medium access control protocol of the station can be ascertained, (ii) the antenna type and pattern, (iii) the switching/steering capabilities of the antenna, and (iv) the direction finding/positioning capabilities of the station.

(7) An association request frame that is transmitted by a station wishing to be admitted to a particular wireless network comprising the information elements described in parts (i), (iv) and (v), and optionally parts (ii) and (iii) depending on the network configuration and the station's capabilities, resulting in a reduction in signaling overheads, comprises (i) the wireless network identifier, as described in part (i) of (5) that was received in the beacon frame, with the intent of signaling the AP that the station wishes to join the WLAN, (ii) the Group identification of the group of beams that covers the station and the station wishes to associate with, as determined by the station by listening for the Beam Start Beacon and the Beam End Beacon, as described in (11) and (12) respectively, (iii) the Beam identification of the specific beam that covers the station and the station wishes to associate with, as determined by the station by listening for the Beam Start Beacon and the Beam End Beacon, as described in (11) and (12) respectively, (iv) the address of the station itself, by which the AP may uniquely identify it in subsequent communications, and (v) information pertaining to the protocol features and the capabilities implemented by the station, as described in (6), with the intent of allowing the AP to determine whether to admit and if so, how best to serve the station.

(8) An association response frame that is transmitted by the access point in response to an association request as described in (7), either accepting or denying the stations request and comprising the information elements described in parts (i), (iv) and (v), and optionally parts (ii) and (iii) depending on the network configuration, the AP's and station's capabilities and the structure of the transmitted association request, described in (7), above, comprises (i) the wireless network identifier as described in part (i) of (5), with the intent of acknowledging the association request made by the station as described in (7), (ii) the group

identification of the group of beams that will be used by the AP in communicating with the station, (iii) the beam identification of the beam that will be used by the AP in communicating with the station, (iv) the address of the station itself, to which the association response is directed, and (v) information pertaining to the status (i.e. the success or failure) of the request and the features and capabilities supported by the AP.

(9) An acquisition request by which the AP may request a station to transmit a pre-determined training sequence for a certain duration with the intent of the AP using this transmission to determine the spatial location of the station in relation to it, comprises (i) the address of the station making the acquisition request, (ii) the address of the station to which the acquisition request is directed, and (iii) the duration of transmission or the length of the training sequence that the addressed station is requested to transmit.

(10) A group-ID assign frame that is sent by the AP to a station, assigning it to a particular group of beams for the purpose of further transmit and receive operations, comprises (i) the address of the AP/the ID of the WLAN, (ii) the address of the station to which the group-ID assign frame is directed to, (iii) the group-ID determined by the AP and assigned to the addressed station, and (iv) the beam identification of the beam that the AP will use in subsequent communications with the addressed station.

(11) A beam start beacon frame that is broadcast by the AP to stations of a particular beam and group, indicating the start of activity for the users of that beam and group, comprises (i) the address of the AP/the ID of the WLAN, allowing stations to identify the source of the transmission, (ii) information pertaining to the capability and the protocol of the wireless network, as described in (6), (iii) the group-ID of the said beam, (iv) the beam-ID of the said beam, (v) the duration for which the said group will be active i.e. the duration during which the AP will transmit and receive from users in the said group before switching to another antenna pattern to serve users of another group, (vi) the frequency at which the relevant beam start beacon will be transmitted, allowing for stations of the said group and beam to synchronize themselves, and (vii) a schedule of the downlink transmissions that the AP will make during the current group duration.

(12) A beam end beacon that is broadcast by the AP to stations of a particular beam and group, indicating the end of activity for that set of users, comprises (i) the address of the AP/the ID of the WLAN, allowing stations to identify the source of the transmission, (ii) information pertaining to the capability and the protocol of the wireless network, as described in (6), (iii) the group-ID of the said beam, (iv) the beam-ID of the said beam, and (v) the duration for which the said group will be inactive allowing those users to adopt a mode of operation facilitating a reduction in power consumption.

(13) A poll+supervised contention announcement frame that is transmitted by the AP to stations of a particular beam defining the schedule of poll-based medium access and contention based access in the wireless medium, comprises (i) a list of polls allocated to individual stations and (ii) an information element declaring the medium for uplink contention based access for a specified duration, known as the supervised contention access duration.

(14) The list of polls allocated to individual stations, as described in part (i) of (13) above, comprises (i) the address of the station to which poll-based access is granted, (ii) the time of the poll i.e. the time at which the station may begin transmitting, (iii) the duration of the poll i.e. the time for which the station may transmit, and (iv) the purpose for the poll or grant, with the intent of indicating to the station that the poll is intended to serve a stream for which bandwidth was previously requested, or to solicit an acknowledgement for a previously transmitted downlink frame etc.

(15) An AP employing an SDMA capable antenna that is able to form 'sector-shaped' beams having the characteristics of (i) a relatively constant gain in the pass-band, minimizing the variance in the received power level for users belonging to that beam and (ii) a sharp roll-off i.e. a narrow transition width, reducing the interference caused by transmissions in one beam to users of another beam thereby allowing the AP to create more closely spaced beams, resulting in a greater spectral efficiency and consequently higher throughput.

(16) A WLAN system using an AP with a multi-beam antenna, as described in (15) that is able to dynamically form beams with the ability to (i) optimize coverage patterns with respect to spatial distribution of individual users

and their traffic loads and (ii) divide the users into groups depending on spatial distribution so as to minimize the variance in the traffic distribution/capacity utilization among users of different groups and beams.

(17) A WLAN system, as described in (16) that uses a timing structure as described in (2) comprises (i) beacon frames, as described in (5) that are periodically transmitted using an omni-directional beam pattern so as to provide coverage/detection to new stations that may exist in areas that are not covered by the existing antenna pattern, as explained in part (i) of (16), (ii) a periodically recurring unsupervised access duration the occurrence of which, new stations may infer from the broadcast beacon, as described in (5), with the intent of facilitating the detection and association of new stations that may not lie in the coverage area of the existing antenna patterns used during the supervised access durations, (iii) the transmission of beam start and beam end beacons, as described in (11) and (12) respectively, in different beams of a group duration, with the intent of announcing the commencement and conclusion of the corresponding group/beam duration and serving to announce the beam and group-ID of the beam to stations in the coverage area, (iv) a station that lies in the coverage area of the existing beams initiating the association signaling, as described in (7) and (8) that is invoked during the supervised contention access mode of the said beam, as described in part (ii) of (27), (v) a station that does not lie in the coverage area of the existing beams initiating the association signaling, as described in (7) and (8) during the unsupervised access duration as described in part (ii), (vi) a station as described in part (iv) being assigned a group and beam-ID using the information elements described in parts (ii) and (iii) of (8), (vii) a station as described in part (v) being assigned a group and beam-ID using the frame described in (10), and (viii) the AP being able to re-assign a station with a new group-ID at any time, using the signaling described in (10).

(18) A method for determining the group and beam-ID of a station, as required to achieve the functionality required by part (vii) of (17) and to handle the case of user mobility, resulting in the invocation of part (viii) of (17), comprises the steps of (i) the AP transmitting an acquisition request frame to a station, as described in (9), (ii) the station responding to the request in part (i) with a predetermined training sequence, (iii) the AP switching between various beams

it is capable of forming and detecting the location of the user as being in the direction of the beam in which the training sequence is received with the highest strength (normalized for beams with different gains), and (iv) alternate to (iii), having determined the initial location of the station, using the method and apparatus as described in (19) to continually update the user location.

(19) A method and apparatus for the AP to continually update the user location based on all uplink transmissions made by the station, allowing the AP to predict the mobility of a station thereby minimizing the use and the overheads incurred by the method in (18), comprises the steps of (i) using a primary beam of characteristic claimed in (15), which is static and is used to receive the transmission sent by the station, (ii) using a secondary steerable beam of characteristic described in (15) that is swept in that vicinity of the primary beam, (iii) determine the angular positions of the secondary beam at which there is a transient in the received power level, and (iv) the angular bisector of the angle subtended by the two beam positions in part (iii) above would yield the location of the station.

(20) A WLAN system using an AP with a multi-beam antenna, as described in (15) that is able to cover the entire space with a set of fixed beams with minimal overlap between adjacent beams, resulting in a system with at least two group-IDs.

(21) A WLAN system as described in (20) that may employ a frame structure comprising only the supervised access mode, resulting in a more efficient use of the medium, comprises (i) the transmission of beam start and beam end beacons, as described in (11) and (12) respectively in the different beams of a group duration, with the intent of announcing the commencement and conclusion of the corresponding group/beam duration and serving to announce the beam and group-ID of the beam to stations in the coverage area, (ii) a station detecting the group/beam ID of the area in which he lies indicating this to the AP by means of the association signaling, as described in (7) and (8), that is invoked during the supervised contention access mode of the said group/beam, as described in part (ii) of (27), (iii) the AP assigning a group/beam-ID to the station in response to the association signaling, as described in part (ii), while accounting for the optimization of traffic distribution of users in different beams across a group in the case of a station that lies in a region of

overlap between beams of two groups, and (iv) the AP being able to reassign a station with a new group-ID at any time, using the signaling described in (10).

(22) The ability of the AP and stations of the WLAN systems described in (16) and (21) to detect and counter for station mobility utilizing the steps of (i) the AP detecting station mobility by observing a succession of missed polls or acknowledgements from a station, (ii) the AP transmitting a new group-ID assign to a lost station in the beams adjacent to the original beam, (iii) the AP upon not being able to re-acquire the station by the method described in part (ii), falling back to the acquisition request signaling as described in (18), and (iv) the station on detecting a high occurrence of missed polls or acknowledgements from the AP and/or the loss of the beam start and beam end beacons of the group that it was assigned to, suspends all power-save activity and waits for the AP to re-acquire it, using the steps in parts (ii) and (iii).

(23) The division of the supervised access duration described in part (ii) of (2) into durations for each group in order to facilitate stations of a given group to power-save until its next activity period, comprises the steps of (i) announcing the start and stop of the group's activity duration using the beam-start and beam-stop beacons, as described in (11) and (12) for users of said group, and (ii) synchronizing the transmission of the beam start and the beam end beacons for all beams of a particular group.

(24) The inclusion of a downlink schedule element in the beam-start beacon, as described in part (vii) of (11) with the intent of (i) indicating the schedule of downlink transmissions - consisting of the destination address, the length of the transmission and the time at which said transmission will be made, and (ii) indicating the end of the downlink transmission schedule i.e. the transmission time for the poll + supervised contention announcement frame, as described in (13), with the intent of allowing stations that are not scheduled to receive any downlink transmissions during a given group duration to power-save for the downlink phase of said group duration.

(25) The aggregation and synchronization of transmissions on different beams within the same group with the intent of preventing collisions in other beams and collisions at the AP itself due to imperfect isolation in practical RF components, into (i) a downlink phase comprising all

downlink transmissions intended for stations of the said group and accounted for in the downlink schedule element described in (24), and (ii) an uplink phase comprising transmissions made from station to the AP using both the polled access and the contention based access mechanisms, as described in parts (ii) and (iii), respectively, of (4).

(26) Aggregation of all downlink transmissions in the downlink transmission phase described in part (i) of (25), with the beam start beacon described in part (vii) of (11), resulting in the reduction of unnecessary overheads and increasing the efficiency of medium usage, by adopting the following steps: (i) the use of a shared preamble transmitted by the AP for the beam-start beacon to which all receivers can synchronize and (ii) the elimination of inter-frame spaces between downlink frames.

(27) The commencement of an uplink transmission phase using the poll + supervised contention announcement which embeds all the uplink polls as described in (13), with the intent of minimizing overheads due to individual polls and not requiring the re-synchronization that would be needed to transmit individual polls, as described in (25), comprises (i) a polled access phase during which stations transmit for the granted/polled duration as contained in the schedule of the poll + supervised contention announcement frame, (ii) a supervised contention phase, which succeeds the polled access phase and is granted till the scheduled transmission of the beam-end beacon.

(28) The use of a guard time that is factored into the schedule described in (14) and in part (i) of (27) that provides for a medium-free duration greater than an RIFS but smaller than a CIFS, between successive polled transmissions, after accounting for the phenomenon of local clock drifts at individual stations.

(29) Methods to minimize the collisions caused by rogue carrier-sense stations that do not confirm to the protocol of the WLAN system as described in (1), comprises the following steps: (i) elimination of the variance between downlink transmission times on different beams of a given group by the transmission of 'dummy' or 'pad' data, so as to equalize the transmission time on all beams, preventing a carrier sense based rogue station from detecting the medium to be free and consequently preventing a transmission from it, and (ii) stations polled for an acknowledgement in

the uplink phase should transmit a negative acknowledgement frame i.e. a station should not ignore an acknowledgement request, thereby not allowing for a gap in the transmission structure to exceed a CIFS duration.

(30) A method to detect and counter for the presence of a rogue station in a wireless network as described in (1), consists of (i) detection of a rogue-station based on the observance of a failed transmission in all beams at the same instant of time, and (ii) upon detecting the presence of a rogue station as in part (i), switching to an unsupervised access mode and signaling the station to move to another channel.

(31) A method for the access point in a system as described in (1) to perform stream admission for a resource reservation request, comprises the steps of (i) resolving the source and destination addresses of the streams to determine if both addresses lie within the same wireless network, and (ii) requiring the AP to ensure resource availability on both groups/beams (as opposed to the legacy case of a system with an omni-directional antenna) before accepting the request.

(32) A method for the users (AP and stations) of the system described in (1) to effect power control thereby limiting the interference caused to other users of the channel and resulting in a reduction of transmit power and consequently a saving in battery life, comprises the steps of (i) embedding the transmit power level used to transmit a particular frame/packet in the transmission, (ii) measuring the received power for a given packet transmission at the receiver, (iii) comparing the values obtained by decoding the information encoded in the transmission of (i), and the value of (ii), and adjusting the transmit power of the next packet sent to the transmitter of the packet in (i) correspondingly.

INDUSTRIAL APPLICABILITY

The present invention can be applied in a 802.11 based WLAN consisting of an AP that is fitted with a multi-beam antenna and is capable of SDMA; and stations, both employing the use of the protocol set out in this text.

BRIEF DESCRIPTION OF DRAWINGS

Figure 1: WLAN network using SDMA - This diagram illustrates an example of a wireless LAN network consisting of three stations and an SDMA capable AP.

Figure 2: Super-frame structure consisting of a supervised access period (AP controlled) and unsupervised access period (distributed control) - This figure illustrates the super-frame structure and how the end of the supervised and unsupervised access modes is signaled.

Figure 3: Protocol stack of the WLAN - This diagram shows the hierarchical protocol stack of the proposed WLAN MAC.

Figure 4: Dynamic Beam forming AP - This figure illustrates an AP that is capable of dynamically creating beams to group users depending on their spatial distribution.

Figure 5: Two Groups of Dynamically formed beams - This figure depicts two sets of beams that may be formed by the AP to cover several users, which cannot be covered, by a single set of beams. The coverage patterns may be optimized based on the user and traffic distributions.

Figure 6: Message sequence for station acquisition using training sequence commands - This diagram illustrates the sequence of messages that is exchanged after association in order to determine the direction of a station and also to subsequently to re-acquire it after a long silence duration or a high loss of acknowledgement or poll frames. As explained in the text, such signaling maybe required depending on the receiver implementation, especially for choose the beams in a Dynamic beam-forming AP (Figure 3).

Figure 7: An apparatus embedded in the AP for constant update of user position - This diagram depicts how two simultaneously formed beams - a primary beam for packet reception and a secondary beam for location update, can be used to dynamically update the user location at the AP whenever there is a packet transmission from the station to the AP.

Figure 8: A method to determine user location - This flowchart describes the steps involved in using the apparatus of Figure 7 for the AP to determine the user location.

Figure 9: Fixed Beam AP - This drawing depicts an AP capable of forming two sets (groups) of three beams each, covering the entire space.

Figure 10: Practical beam pattern of two adjacent sector shaped beams - This diagram depicts the overlap that occurs when trying to achieve complete coverage between two adjacent beams, due to the fact that a beam with a zero transition width (vertical roll-off) would require infinite antenna elements. It also shows the interference caused by sidelobes from one beam space to another.

Figure 11: HMSC of a station startup sequence - This figure summarizes the start-up sequence adopted by a station.

Figure 12: Timing structure of the supervised access mode - This figure depicts an example of the timing structure of the supervised access mode, based on a system with two groups and 3 beams per group. The time is divided between the two groups, the start and end of which are signaled by Beam Start and Beam End Beacons, respectively.

Figure 13: Uplink and downlink transmission structure during the supervised access mode - This figure depicts an example of the supervised access mode for one of the groups. In this example, the group's duration is divided into one uplink and one downlink phase. The figure illustrates the synchronization between the uplink and downlink transmissions from different beams to and from the AP.

Figure 14: Uplink and downlink transmission structure (with dummy/pad transmissions) during the supervised access mode - This drawing extends the example shown in Figure 12, illustrating how dummy/pad transmissions can be used during the downlink phase to synchronize the transmission duration on all beams so as to prevent a rogue station from accessing the medium.

DESCRIPTION OF REFERENCE NUMERALS

101 Access point
102,103,104 Station
105,106,107 SDMA beam
201 Beacon frame
202 Super-frame
203 Supervised access mode
204 Unsupervised access mode
205 Supervised access end frame
206 Unsupervised access end frame
301 Contention-based access mechanism
302 Poll-based access mechanism
303 Beam access coordinator
304 Medium access control (MAC) layer

305 Physical layer
306 Management entity

5 DRAWINGS

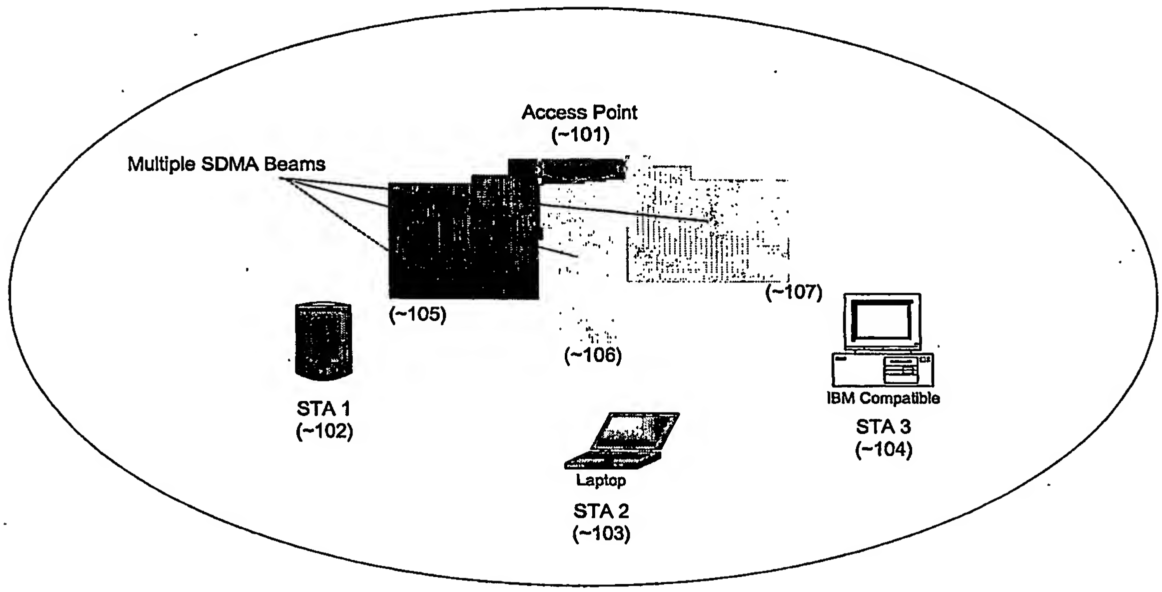


Figure 1

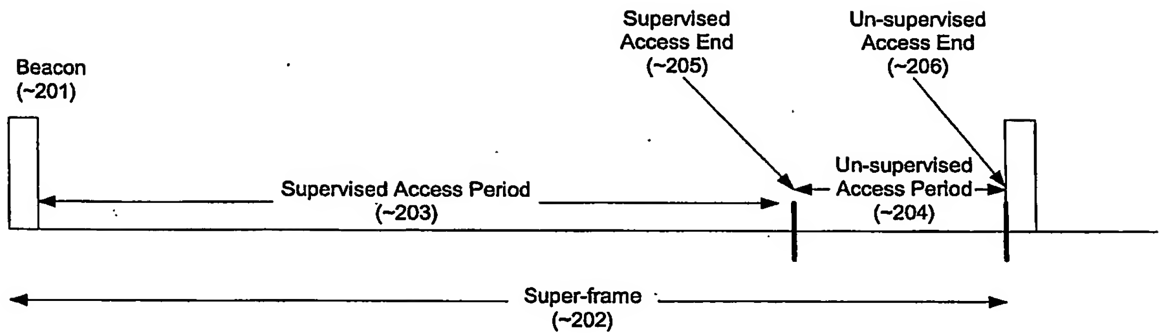

Supervised
Access End
(~205)
Un-supervised
Access End
(~206)
Beacon
(~201)
Supervised Access Period
(~203)
Un-supervised
Access Period
(~204)
Super-frame
(~202)

Figure 2

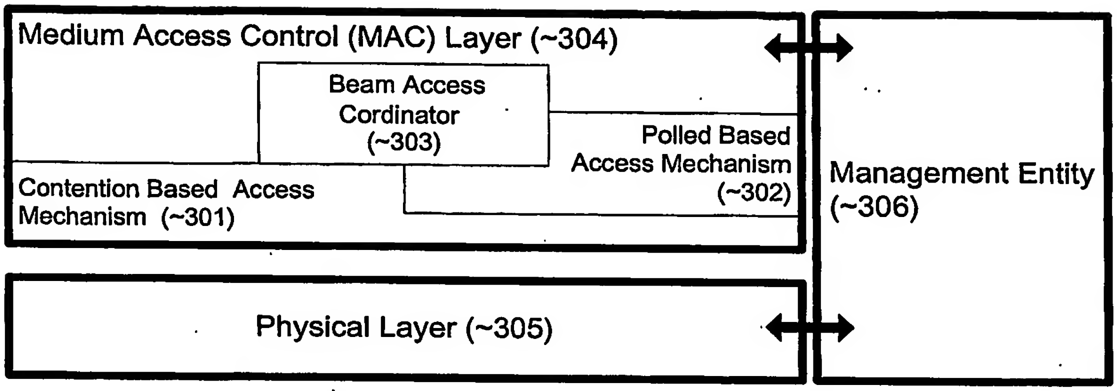

Medium Access Control (MAC) Layer (~304)
Beam Access Cordinator (~303)
Polled Based Access Mechanism (~302)
Contention Based Access Mechanism (~301)
Management Entity (~306)
Physical Layer (~305)

Figure 3

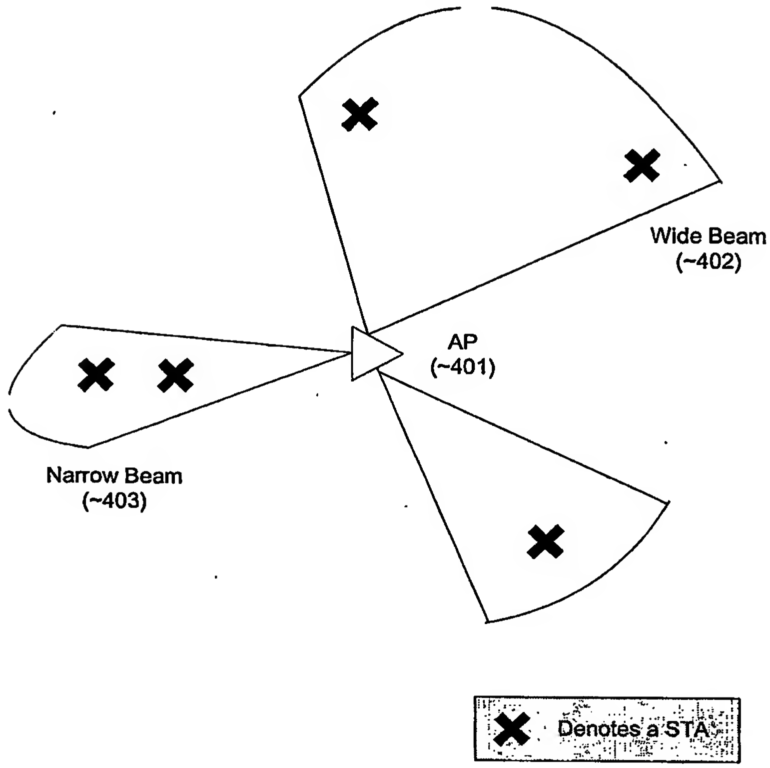


Figure 4

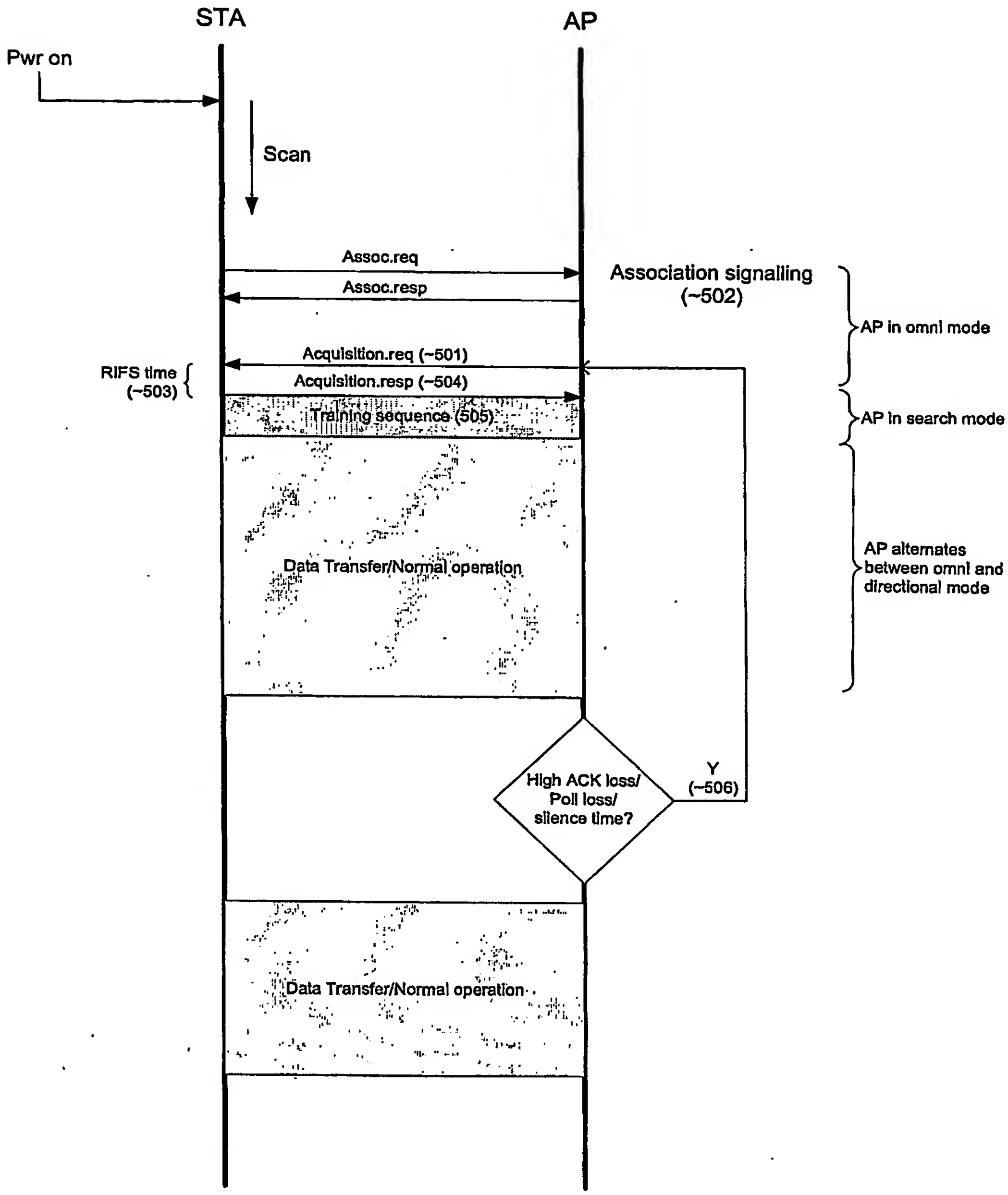

STA
AP
Pwr on
Scan
Assoc.req
Assoc.resp
Association signalling
(~502)
AP in omni mode
Acquisition.req (~501)
RIFS time
(~503)
Acquisition.resp (~504)
Training sequence (505)
AP in search mode
Data Transfer/Normal operation
AP alternates
between omni and
directional mode
High ACK loss/
Poll loss/
silence time?
Y
(~506)
Data Transfer/Normal operation

Figure 6

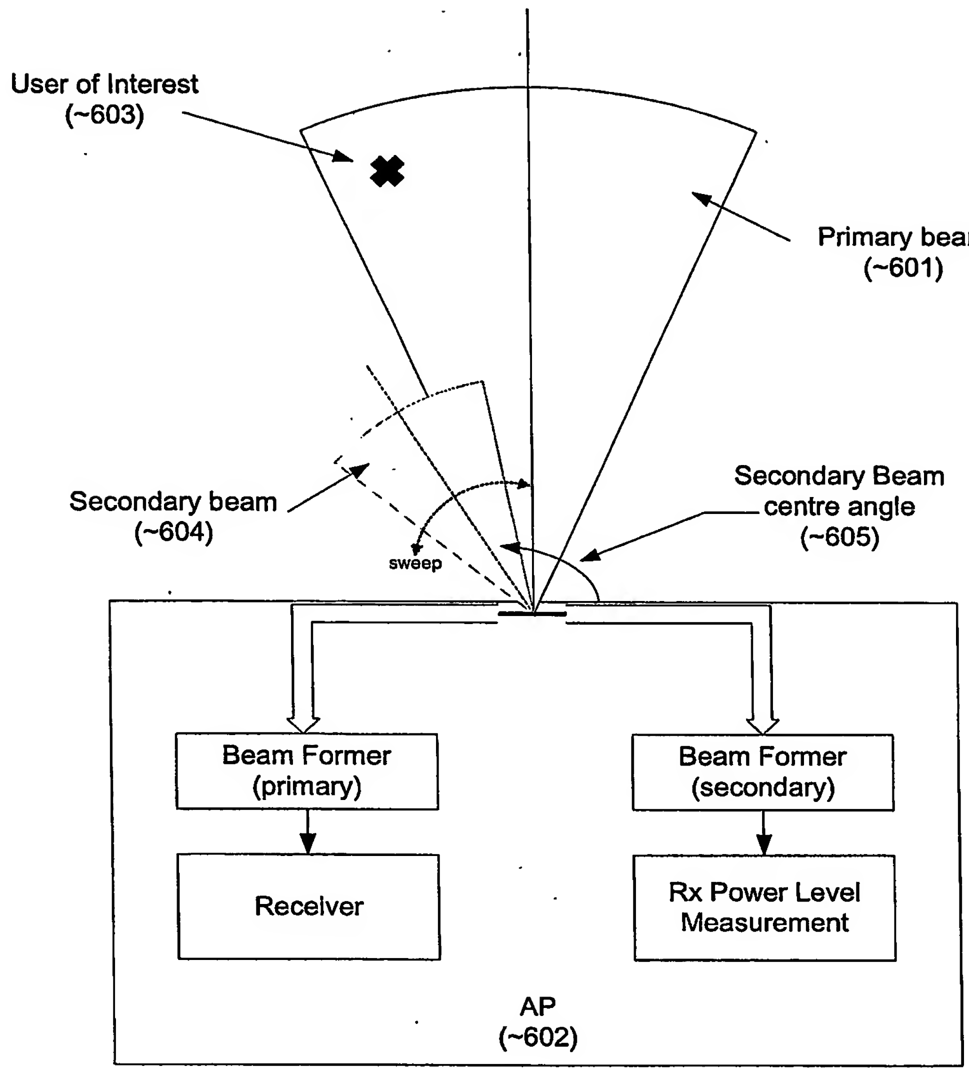

User of Interest
(~603)
Primary beam
(~601)
Secondary beam
(~604)
sweep
Secondary Beam
centre angle
(~605)
Beam Former
(primary)
Beam Former
(secondary)
Receiver
Rx Power Level
Measurement
AP
(~602)

Figure 7

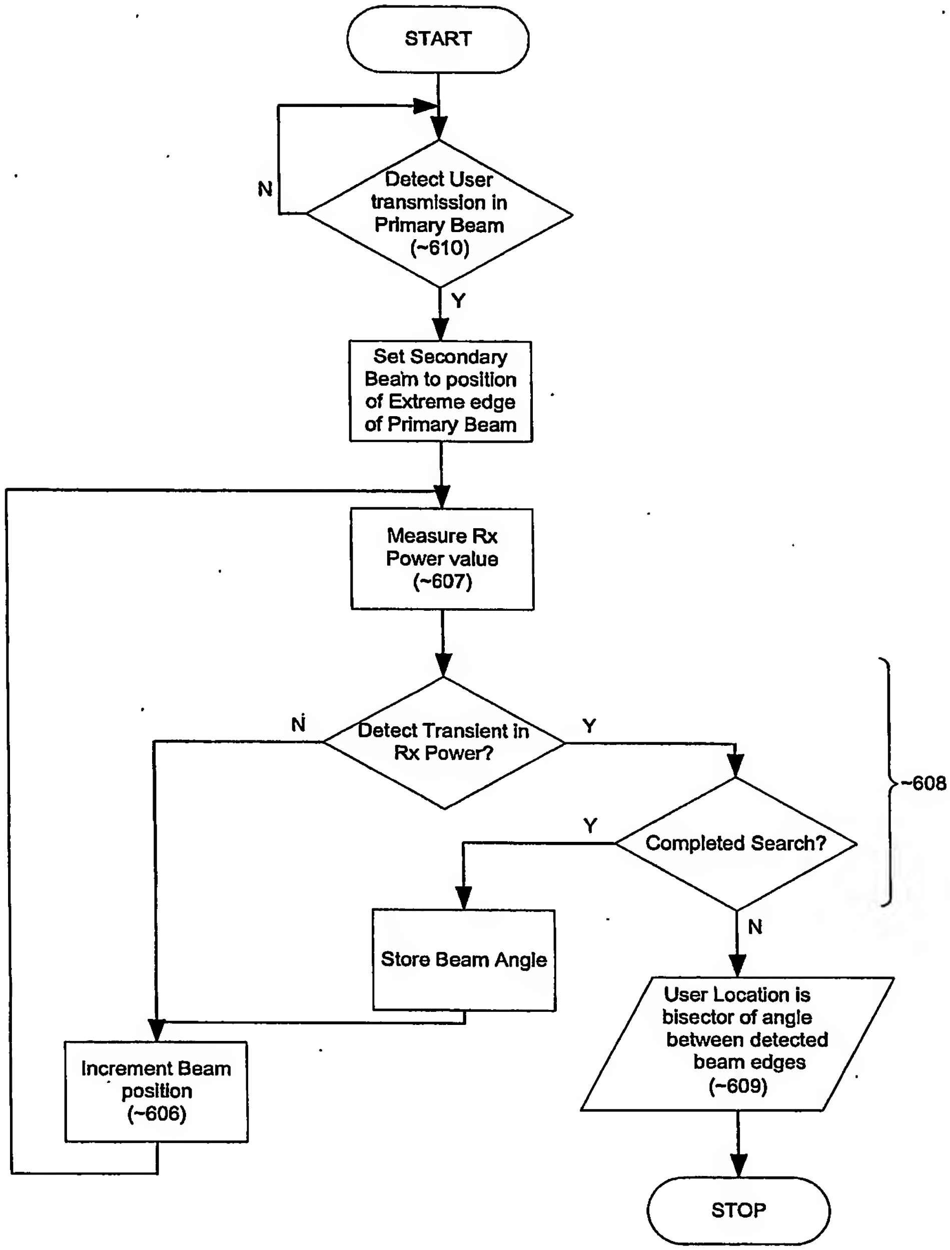

START
Detect User transmission in Primary Beam (~610)
N
Y
Set Secondary Beam to position of Extreme edge of Primary Beam
Measure Rx Power value (~607)
Detect Transient in Rx Power?
N
Y
Completed Search?
Y
N
~608
Store Beam Angle
User Location is bisector of angle between detected beam edges (~609)
Increment Beam position (~606)
STOP

Figure 8

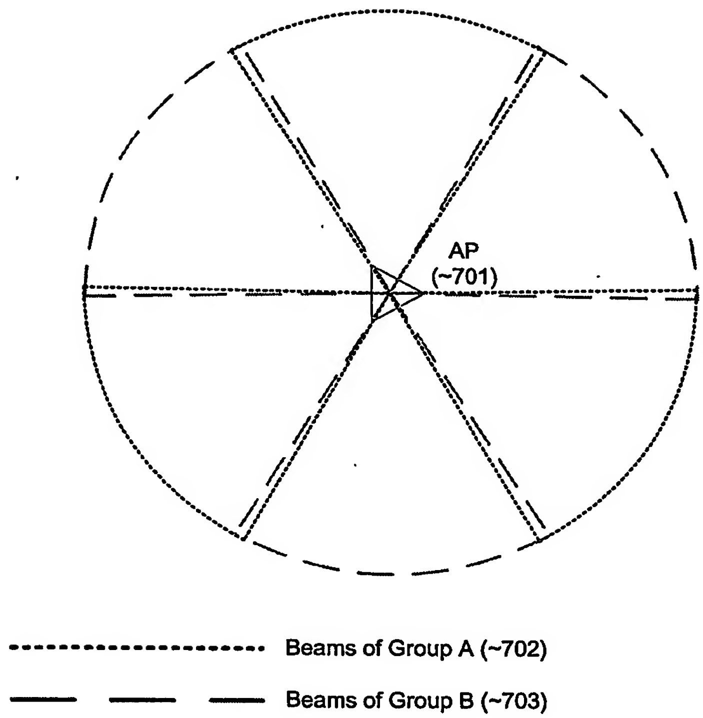


Figure 9

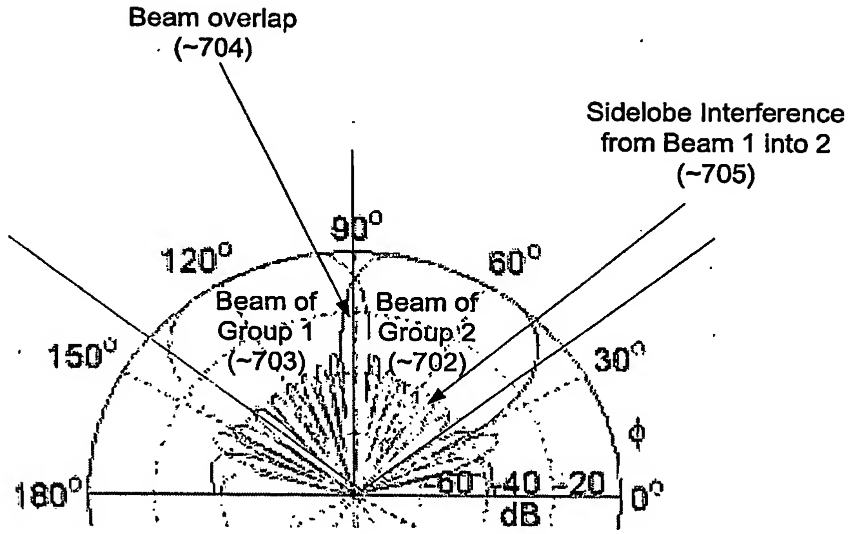

Beam overlap
(~704)
Sidelobe Interference
from Beam 1 into 2
(~705)
90°
120°
60°
150°
30°
Beam of
Group 1
(~703)
Beam of
Group 2
(~702)
φ
180°
-60
-40
-20
0°
dB

Figure 10

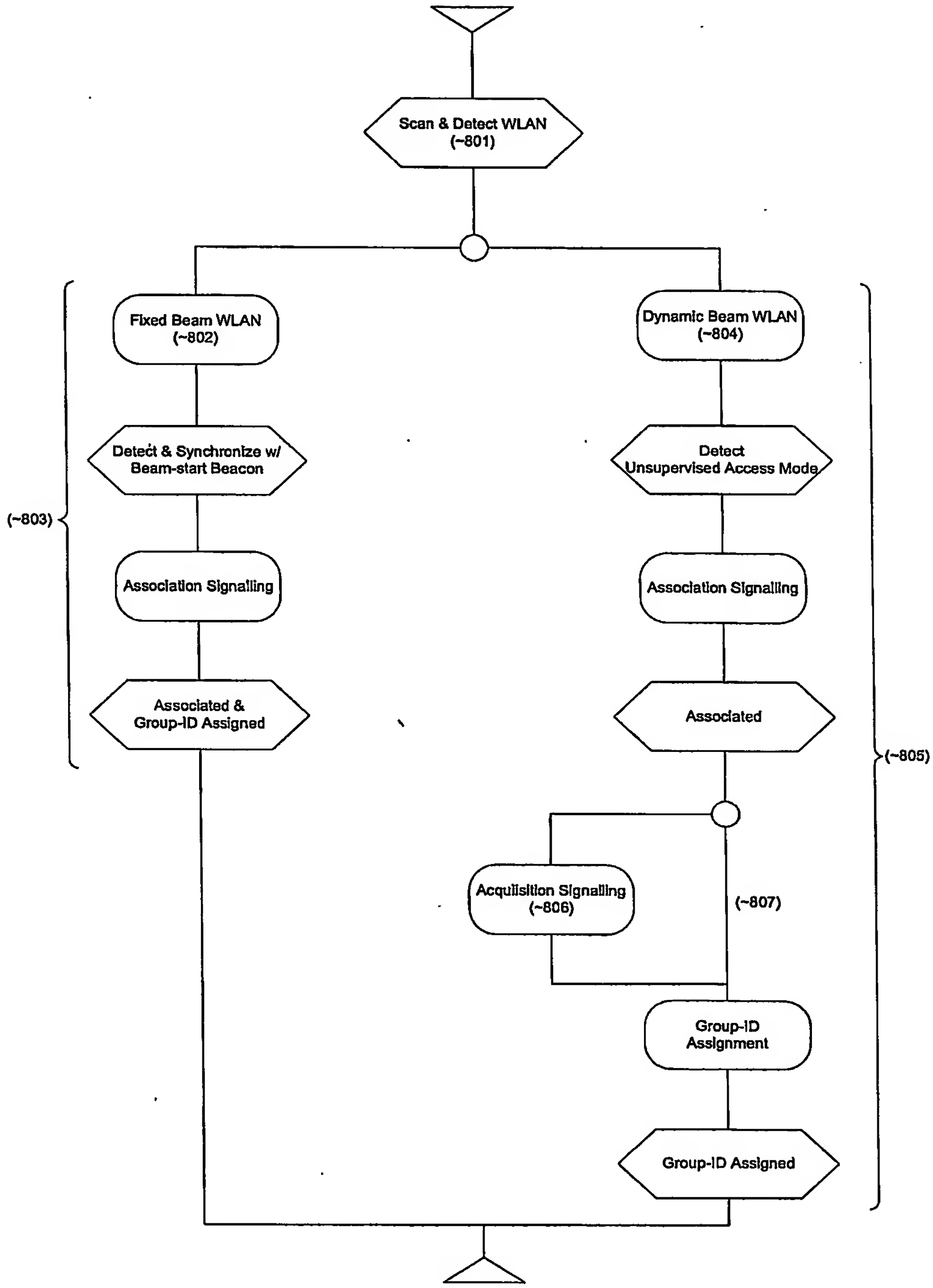

Scan & Detect WLAN
(~801)
Fixed Beam WLAN
(~802)
Detect & Synchronize w/
Beam-start Beacon
(~803)
Association Signalling
Associated &
Group-ID Assigned
Dynamic Beam WLAN
(~804)
Detect
Unsupervised Access Mode
Association Signalling
Associated
(~805)
Acquisition Signalling
(~806)
(~807)
Group-ID
Assignment
Group-ID Assigned

Figure 11

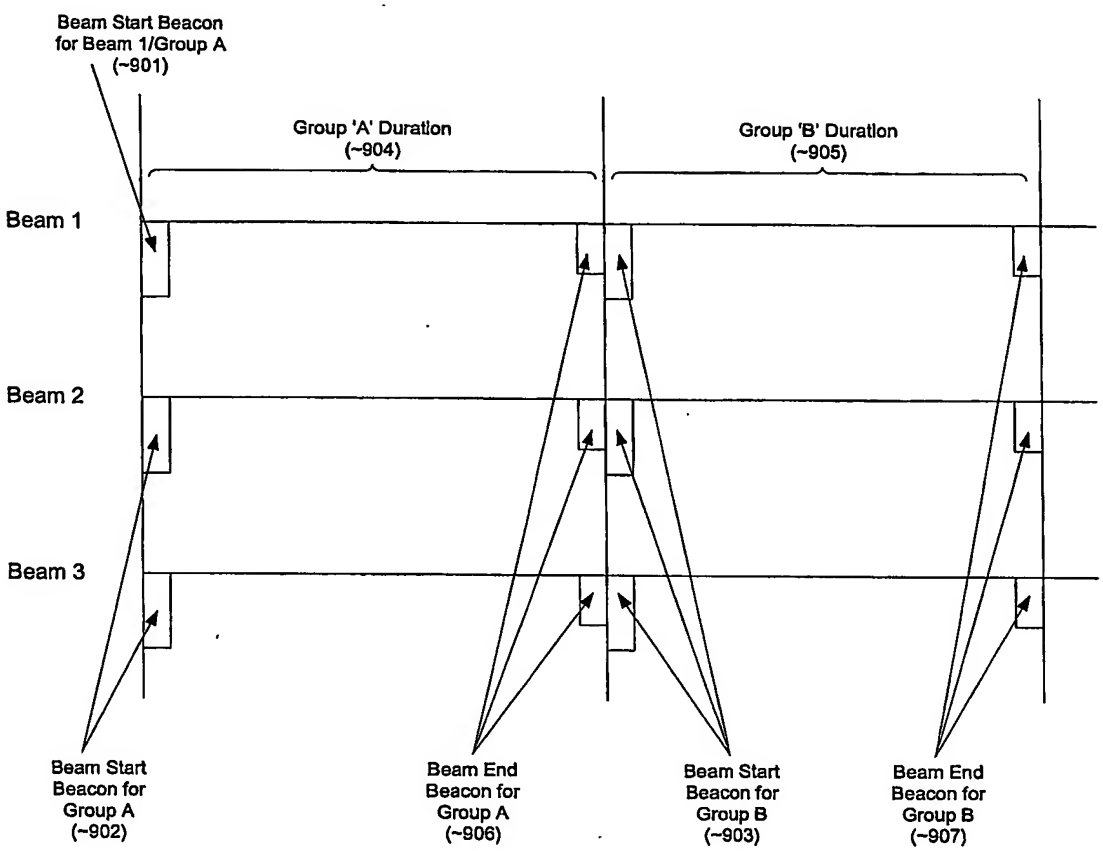

Beam Start Beacon for Beam 1/Group A (~901)
Group 'A' Duration (~904)
Group 'B' Duration (~905)
Beam 1
Beam 2
Beam 3
Beam Start Beacon for Group A (~902)
Beam End Beacon for Group A (~906)
Beam Start Beacon for Group B (~903)
Beam End Beacon for Group B (~907)

Figure12

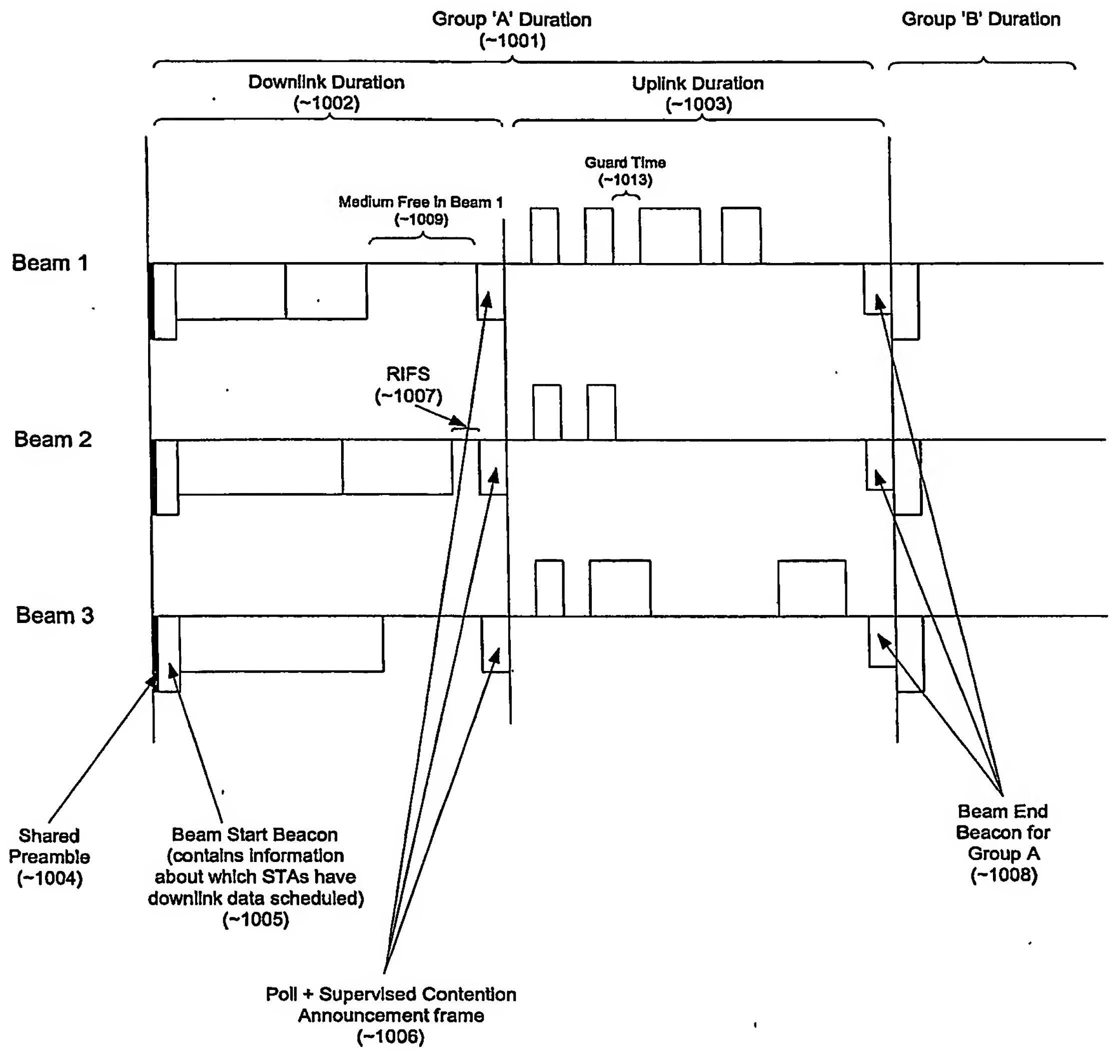
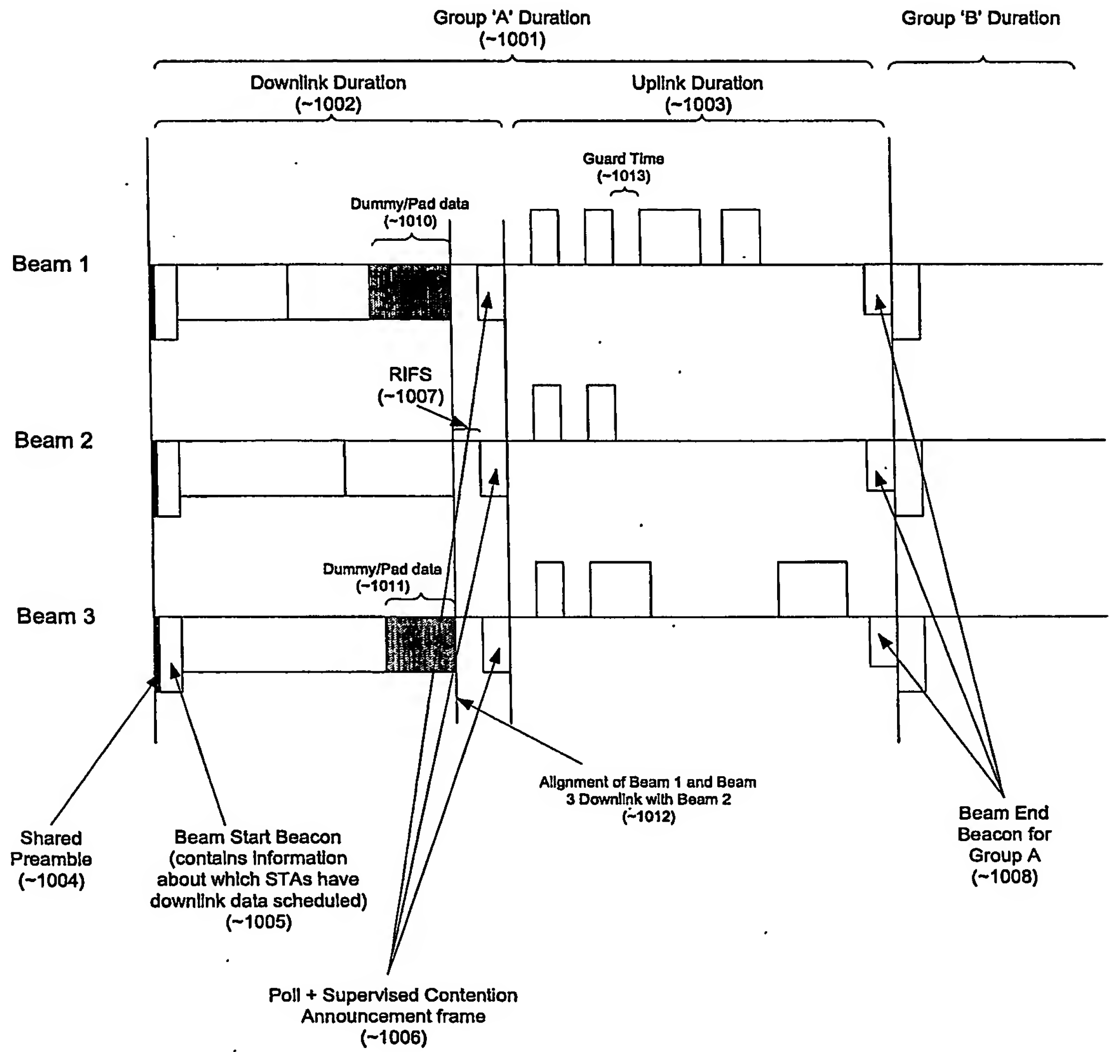

Group 'A' Duration
(~1001)
Group 'B' Duration
Downlink Duration
(~1002)
Uplink Duration
(~1003)
Guard Time
(~1013)
Medium Free in Beam 1
(~1009)
Beam 1
RIFS
(~1007)
Beam 2
Beam 3
Shared
Preamble
(~1004)
Beam Start Beacon
(contains information
about which STAs have
downlink data scheduled)
(~1005)
Beam End
Beacon for
Group A
(~1008)
Poll + Supervised Contention
Announcement frame
(~1006)

Figure 13



Group 'A' Duration
(~1001)
Group 'B' Duration
Downlink Duration
(~1002)
Uplink Duration
(~1003)
Guard Time
(~1013)
Dummy/Pad data
(~1010)
Beam 1
RIFS
(~1007)
Beam 2
Dummy/Pad data
(~1011)
Beam 3
Alignment of Beam 1 and Beam 3 Downlink with Beam 2
(~1012)
Shared Preamble
(~1004)
Beam Start Beacon (contains information about which STAs have downlink data scheduled)
(~1005)
Beam End Beacon for Group A
(~1008)
Poll + Supervised Contention Announcement frame
(~1006)

Figure 14

NAME OF DOCUMENT

ABSTRACT

[Problem] To provide methods and systems that may be applied with the intent of achieving high throughput in WLANs.

[Solving Means] At the core of the invention is the use of a SDMA capable multi-beam antenna system at the AP of the WLAN. A system based on two different types of antenna classes - dynamic beam forming, and fixed-beam antennas is described. A mechanism and protocol for achieving simultaneous transmissions to and from the SDMA AP, thereby improving the spectral efficiency and consequently attaining a higher throughput is described in detail. Based on the knowledge that the present day WLAN MAC proves a major limitation in throughput, certain MAC enhancements (that may also be applied independent of SDMA) are also described. Power-save and Power-control techniques that result in better battery performance and smaller terminal design; and reduced interference on the channel are disclosed. The invention also addresses the issue of backward compatibility with legacy devices that may implement a protocol that is a subset of that described by the present invention.

[Selected Figure] Figure 2

特願２００３－２７６９８７

出　願　人　履　歴　情　報

識別番号　［０００００５８２１］

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